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1. Introduction

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Welcome to the Second Pulse of the Delta Report

The Chair of the Delta Stewardship Council, Phil Isenberg, asked attendees at the State of the Estuary (SOE) 2011 conference this question: “How do we get the courts out of trying to run water operations, ecosystem restoration and second-guessing the judgment of scientists?”

For one, this requires improved collaboration and communication among the various Delta stakeholders outside the courts. It also requires a common basis of reliable and objective scientific information. Sharing understanding about the Delta’s problems through joint fact-finding processes, while not the only requirement, creates opportunities for transcending positions and a shared commitment to possible solutions.

The Delta Regional Monitoring Program (RMP)’s goal is to contribute in both ways: by becoming a forum for collaboratively defining and solving water quality issues in the Delta and by building a common foundation of sound scientific information. The Pulse of the Delta intends to do its part to advance the debate on the issues, by making information on important water quality topics available to Delta managers. At SOE 2011, Friends of the Estuary awarded the Pulse of the Delta with an Outstanding Environmental Project Award in the category of Public Involvement and Education. Receiving the award was a tremendous encouragement for our work and we are feeling obliged to work even harder at meeting and exceeding expectations and establishing an access point to good water quality information for managers, decision-makers, scientists, and the general public.

In essence, we are developing the Pulse of the Delta as a “voice” for the fledgling Delta RMP that helps to meet its goals of better defining water quality issues of regional concern and improving the quality and efficiency of water quality monitoring information. This second edition of the Pulse of the Delta includes the following sections:

Key topic article: introduces this year's theme, *Linking Science and Management through Regional Monitoring.*

Management Update: this section provides in-depth updates on the Delta RMP development, U.S. Environmental Protection Agency (EPA)'s new Bay-Delta initiative, and the development of Nutrient Numeric Endpoints for Estuaries. And as a new feature, it now also provides an overview of the regulatory status of pollutants of concern.

Feature articles: this year's articles on methylmercury in wetlands and the Interagency Ecological Program (IEP)'s future provide overviews of important scientific developments related to salient Delta management issues.

Status and Trends Update: this edition introduces a new Status and Trends section with updates on important monitoring results and lead indicators for the Delta. The Status and Trends section was made possible thanks to significant in-kind contributions by the IEP, U.S. Geological Survey (USGS), the Central Valley Regional Water Board, California Department of Fish and Game (DFG), California Department of Water Resources (DWR), and scientists at the University of California (U.C.) Berkeley, U.C. Davis, and San Francisco State University (SFSU)'s Romberg Tiburon Center.

Science for Managers That Brings Economies of Scale

A strong link between science and management is critical for defining and solving water quality issues in the Delta. Good decisions on policies and actions depend on reliable and objective knowledge, based on sound science and high-quality data that specifically address an important question, collected using an appropriate method and sampling design, at appropriate scales of time and geography. Experience in other regions has shown that good science at the regional scale improves regulatory decisions about water quality (see **Key Topic article, page XX**). It provides a solid foundation for water quality decisions such as TMDLs (Total Maximum Daily Loads) and other regulatory actions affecting the entire Delta: permit limitations, 305(b) reporting, 303(d) listings, application of the Antidegradation Policy, adjustments to the Irrigated Lands Regulatory Program, to name a few. It serves as a clear path toward solutions to Delta water quality issues.

Benefits can be realized based on the economies of scale a Delta RMP brings. In other regions, a shift from isolated monitoring of individual discharges to pooling of resources provided the opportunity to perform comprehensive, consistent monitoring across waterbodies and watersheds with minimal administrative costs. Several other benefits resulting from economies of scale in other regions include coherent data management systems that facilitate assessments beyond individual program boundaries, an overarching quality assurance program, and effective reporting. Moreover, pooling of resources helps to identify and respond to problems in an adaptive manner.

2. Key Topic

Monitoring Through Regional Partnerships: A Well-Proven Win-Win-Win for Managers, Regulators, and the Environment

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Managers responsible for water quality, aquatic habitat, and natural resources in the Sacramento-San Joaquin Delta have struggled to assemble data from the varied range of sources needed to create a picture of conditions in the Delta and to understand the processes that affect them. They are not alone in this effort. Over two decades ago, in 1990, a National Academy of Sciences report on marine monitoring in southern California found that, despite extensive and technically sophisticated monitoring efforts, it was impossible to present a picture of conditions in the Southern California Bight as a whole. The large majority of monitoring was concentrated around individual waste discharges, with little attention to cumulative impacts or the health of larger-scale ecosystems. Despite the collection of high-quality data, differences among monitoring programs hindered efforts to integrate data from multiple programs. Even more important, managers had no systematic structure for asking questions that cut across multiple programs and encompassed larger areas. There was therefore little if any ability to describe conditions or track changes at large scales or to assess cumulative impacts from multiple sources. This finding inspired a coordinated effort among regulators and dischargers to develop the Southern California Bight Regional Monitoring Program, which has expanded since the early 1990s to include over 100 participants and to encompass processes that extend from the inland boundaries of coastal watersheds across the continental shelf.

Since 1990, a growing awareness that the problems identified in the Southern California Bight were widespread led to the initiation of many other regional monitoring programs throughout the state (**Table 1**).

These and other similar programs vary in scale, from individual watersheds to a statewide scope that focuses on specific habitat types or issues. However, they all share three core objectives:

- Assessing conditions, and trends in conditions, consistently across larger geographic scales
- Improving the quality and coordination of monitoring and assessment methods
- Maximizing the value of existing monitoring efforts by strengthening their links to decision making

This clear focus has enabled these programs to achieve significant successes, such as updating management priorities, improving regulatory frameworks, and enhancing the quality of data.

Adjusting management priorities

In southern California, the Southern California Stormwater Monitoring Coalition, Los Angeles River Watershed Monitoring Program, and San Gabriel River Regional Monitoring Program have documented unexplained water column toxicity as well as lower than expected biological community scores in natural streams with no direct sources of contamination. In contrast, toxicity is lower than expected in urban areas. These counterintuitive findings have resulted in adjustments to management priorities (e.g., less concern about toxicity in urban areas) and emphasized the need to add objectives for biological condition to the previous heavy reliance on chemical-specific water quality criteria. Michael Lyons is the Surface Water Ambient Monitoring Program (SWAMP) coordinator at the Los Angeles Regional Water Quality Control Board responsible for spearheading the development of the two regional watershed programs. He says, “Both of these watershed programs are great examples of the benefits of partnerships…I am really happy with them because everyone involved feels they are producing much better results than in the past.”

In the Monterey Bay area, “CCLEAN has provided information that has helped dischargers and water quality regulators focus management actions on the areas that will provide the greatest benefits to stakeholders", says CCLEAN Director Dane Hardin. For example, after detecting the presence of DDT and PCB contamination in sediments of Monterey Bay, results from the program were used to estimate the relative contributions of these contaminants from river and wastewater discharges, information that can be used to identify and prioritize corrective actions.

Improving regulatory frameworks

In the San Francisco Bay, Tom Mumley of the Regional Water Quality Control Board recalls that improved data from the RMP that were trusted by all parties supported the development of "site-specific objectives for copper that were protective of beneficial uses but provided relief from what would otherwise have been costly effluent limits for all dischargers to the Bay." The RMP also tracked a declining Bay-wide trend in water column toxicity that allowed management agencies to adjust their priorities more quickly than they otherwise would have been able to. According to Mike Connor, General Manager of the East Bay Dischargers Authority (and formerly Executive Director of SFEI), one important benefit of the RMP is that, "in the absence of data, regulatory agencies are often overly conservative in their assumptions. Regional monitoring provides a way to conduct joint fact finding that allows everyone to focus on data that are mutually acceptable."

SWAMP's statewide survey of fish tissue contamination in lakes confirmed the magnitude of problems due to legacy pollutants such as mercury, DDT, and PCBs, helping managers at the State Water Resources Control Board revise their thinking about how to address the problems associated with each contaminant. For example, reliable information about the broad extent of mercury contamination prompted more serious consideration of a single statewide Total Maximum Daily Load (TMDL) rather than multiple local TMDLs. Similarly, widely trusted data from the RMP allowed adoption of load allocations and implementation strategies for the PCBs TMDL that were less restrictive and costly than what would have been possible without the RMP.

Regional programs also provide a structured framework for the more systematic analysis of compliance monitoring data. Scott Johnson, the consultant who conducts the Los Angeles and San Gabriel Rivers programs, notes that these programs for the first time analyzed all receiving water data collected by NPDES dischargers over the long term. This documented the extremely low number of exceedances and thus the effectiveness of management policies and treatment technologies.

Better and more reliable data

Regional monitoring programs' ability to conduct larger-scale assessments depends on the comparability of data across the region—apples should be compared to apples. Regional programs thus invest effort in developing and implementing coordinated sampling and analysis methods and in ensuring comparable levels of quality assurance and control (QA/QC). For example, all members of the Southern California Bight Regional Monitoring Program participate in laboratory intercalibration studies. These have proved so valuable in establishing confidence in the reliability of monitoring data that some dischargers are now required by permit conditions to send all samples to laboratories that have participated in intercalibration efforts. Similarly, several laboratories operated by municipal treatment plants participated in intercalibration studies during the early phases of the Bay RMP and were able to take on analysis of sediment samples themselves.

Coordinated sampling methods not only increase confidence in routine monitoring data. They also allow programs to rapidly ramp up special studies without the need for large amounts of up-front planning that would otherwise be necessary to synchronize sampling designs and methods. Eric Stein, the scientist at the Southern California Coastal Water Research Project (SCCWRP) who coordinates the SMC's efforts, describes how the SMC was able to implement an off-the-shelf rapid response plan for examining the effects of the large fires that swept much of southern California in 2007. These special studies examined the fires' impacts on contaminant inputs and water quality, information useful for mitigating effects on downstream areas and for understanding post-fire changes in compliance monitoring data. As another example, the San Gabriel River program was able to quickly implement a sediment sampling program for polybrominated diphenyl ethers (PBDEs) to follow up on the 2008 Bight Program's finding of high concentrations of these emerging contaminants in estuaries and harbors throughout the region. This sediment sampling program will help to determine the scale of contributions from the watershed.

Regional programs typically extend monitoring coverage to areas that were undersampled by traditional compliance monitoring programs. As mentioned above, this can result in surprises, such as the finding of lower-than-expected biological community scores in undeveloped areas. One pleasant surprise in the Los Angeles and San Gabriel Rivers watersheds was the discovery of sites with very high habitat quality, despite intense pressures from development, water management, and dense human population in much of each watershed. These results, because they were based on highly reliable monitoring data, changed assumptions about the possibility of preserving high quality habitat in developed watersheds.

Multiple pathways to success

One key ingredient to these successes is the active and collaborative involvement of multiple parties with differing and complementary perspectives and resources. This is a stark contrast to the traditional program structure in which a single agency acts independently, focused on a relatively narrow range of issues. However, there is no single recipe, and successful collaborative programs have followed a number of different pathways as they transition to a more broadly based and collaborative structure.

Many permits now include a requirement for participation in existing regional monitoring efforts. For example, NPDES permits for all major dischargers in southern California require both routine compliance monitoring and regional monitoring and also provide for short-term special studies. Some programs have resulted from permit requirements that give major dischargers the responsibility to spearhead development of regional monitoring plans and programs. In some instances, regulatory agencies allow resources usually spent on compliance monitoring to be either temporarily or permanently reallocated to regional-scale questions. Some regional programs, such as the SMC, begin as voluntary collaborative efforts that after a time become incorporated into permits. Some, such as the two watershed programs in the table above, operate relatively informally, while others, such as the larger Bight Program and San Francisco Bay RMP, operate much more formally. In all cases, however, they remain tightly focused on the three core objectives described above.

Moving forward in the Delta

A multi-party, collaborative regional monitoring program for the Delta, as envisioned by the Delta RMP, would offer enhanced opportunities for partnering among the

Delta's many monitoring and assessment efforts, opportunities not provided by traditional compliance and/or single agency monitoring approaches. It would provide the ability to more efficiently and comprehensively address critical questions about water quality and aquatic habitats and achieve the types of benefits described above. Most important, coordinated, Delta-wide information will enhance understanding of the nature of the threats facing the Delta and improve the quality of decision making about how to meet these threats.

Table 1.

Representative regional monitoring programs active in California. RMP: Regional Monitoring Program in San Francisco Bay, Bight Program: Southern California Bight Regional Monitoring Program, Lake Tahoe: Tahoe Basin Regional Stormwater Monitoring Program (RSWMP), CCLEAN: Central Coast Long-term Environmental Assessment Network, SMC: Southern California Stormwater Monitoring Coalition, LA&SG Rivers: Los Angeles River Watershed Monitoring Program and San Gabriel River Regional Monitoring Program, NGO: Non-governmental organization, JPA: Joint powers authority.

	RMP	Bight Program	Lake Tahoe	CCLEAN	SMC	LA & SG Rivers
Start date	1993	1994		2001	2001	2006 / 2008
Operational Lead	NGO	JPA	NGO	Consultant	JPA	NGO
Budget (approximate)	$3M	$8 – 9M	$236K	$350-400K	NA	$0.7M
Program Structure	Three-tiered • Steering committee • Technical review committee • Issue workgroups	Two-tiered • Steering committee • Issue workgroups	Working group	Working group	Two-tiered • Steering committee • Participants	Working group
Participants	Dischargers Regulators Scientists	Dischargers Regulators Resource managers	Regulators Resource managers Planning agencies	Dischargers Regulators	Dischargers Regulators	Dischargers Regulators Local government

Environmental groups	Scientists Environmental groups	Environmental groups

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Sidebars

1. Objectives Framework

The proposed core questions and associated monitoring questions of the Delta RMP.

Objectives Framework **STRAW QUESTIONS** ***Core Questions*** **Associated Monitoring Questions**
STRAW CORE QUESTION 1: *Are contaminants in the Delta potentially at levels of concern?*
Associated Monitoring Question 1-1. *What is the spatial and temporal distribution of contaminants?* Associated Monitoring Question 1-2. *What are appropriate water quality guidelines?* Associated Monitoring Question 1-3. *Are there particular regions of concern?*
STRAW CORE QUESTION 2: *What are the sources, pathways, loadings, and processes leading to water quality impacts in the Delta?*
Associated Monitoring Question 2-1. *Which sources, pathways, loadings, and processes contribute most to impacts?* Associated Monitoring Question 2-2. *What are the effects of management actions?*
STRAW CORE QUESTION 3: *What are the projected water quality conditions and associated impacts in the Delta?*
Associated Monitoring Question 3-1. *What is the water quality forecast under various management scenarios?*

3. MANAGEMENT UPDATE

a. Laying the Foundation for the Delta Regional Monitoring Program:

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Highlights

- ⇨ Initially, the Delta Regional Monitoring Program will focus on making the required monitoring of regulated dischargers more purposeful and efficient, to free up resources to address larger regional questions.
- ⇨ Focusing on some of the identified deficiencies will further engage stakeholders, enhance the capabilities of the Regional Board, and provide a solid base to continue to develop an effective and efficient regional monitoring program.
- ⇨ There is general agreement that we are not utilizing all readily available information and, perhaps, changes can be made to the monitoring of particular constituents.
- ⇨ There appear to be numerous opportunities to leverage, combine, or alter the monitoring in order to provide better regional information
- ⇨ Promoting effective and efficient compliance monitoring will require identifying specific questions to answer.
- ⇨ During the pilot phase, the main focus will be on the question: "Are contaminants in the Delta at levels of potential concern?
- ⇨ Identifying locations where multiple discharges enter receiving water in close proximity and coordinating monitoring to address questions about

localized cumulative impacts will apply regional monitoring concepts on a small scale and help to identify challenges as we broaden the reach.

⇨ The ultimate goal of the Delta RMP is to provide comprehensive monitoring of contaminants in the Delta to ensure protection of beneficial uses.

The Delta RMP: Comprehensive assessments of the Delta

Though a number of monitoring programs currently sample in the Delta, the work lacks the overarching goals and perspective necessary to effectively address the Delta's current problems. The Delta RMP is being established to enact coordinated and comprehensive monitoring, analysis and reporting, in order to provide the information necessary to steward the Delta's resources or future generations. More information on the reasons and goals for the Delta RMP can be found in last year's *The Pulse of the Delta* article *Delta RMP: Re-Thinking Water Quality Monitoring in the Delta.*

The Initial Focus of the Delta RMP

The RMP development process began with a wide vision – regularly compiling, assessing, and reporting information about contaminants and their effects within the Delta, using data collected by a wide range of agencies and programs. Last year, the first Pulse of the Delta report the highlighted intentions and opportunities of the RMP. It also represents an example of the clear, accessible reports that the Program intends to provide. Since the release of the first Pulse, we have been developing the overall framework, governance structure, and monitoring objectives of the RMP. Workgroups will guide pilot projects, answer questions, and suggest improvements, while helping to find the most suitable approach to implement the long-term program .

A goal of the RMP is to coordinate monitoring and combine the data collected under a variety of programs, but it became very clear early in the development process that it would not be possible to develop a complete program in a single step because of the need for changes to many different programs spread across a variety of different agencies, jurisdictions, and interests. After exploring the challenges inherent with such changes, the Delta RMP planning team, under the combined direction of stakeholders and staff from the Central Valley Regional and State Water Boards, decided to step back and narrow the coordination focus to compliance monitoring programs under the direct authority of the Regional Water Board (**Figure 1**). While these dischargers, regulated by the National Pollutant Discharge Elimination System (NPDES) permit program, are not alone in conducting monitoring, they are a distinct group that provided a tangible starting point in which small changes could possibly reap big benefits. Reviewing their receiving water monitoring requirements was a logical place to start.

The Delta RMP Planning Team and the Water Boards staff have frequently heard criticisms of the inefficiency of receiving water monitoring programs (required programs to monitor the waters that receive wastewater discharges), particularly in providing information for regional assessments. To better understand these complaints, Thomas Jabusch (Aquatic Science Center) and Brock Bernstein (consultant) contacted dischargers to identify specific issues and the benefits of addressing those issues. Dischargers often saw little purpose in their monitoring requirements and lamented the rigidity in current permits that prevents them from applying adaptive monitoring approaches. Focusing on these issues will further engage dischargers, enhance the capabilities of the Regional Board, and provide a solid base to continue to develop an effective and efficient regional monitoring program.

As we move forward, we intend to implement some of the ideas that came out of the discussions with stakeholders and lay a strong foundation for a long-term program. We will continue to focus on particular aspects and develop the program in phases that build upon each other. To help us, we have enlisted staff throughout the various programs at the Regional Water Board and continue to work with staff at the State Water Board on data management issues (**Sidebar: CEDEN: Making Strides Towards Better Data Comparability and Access**). In addition to working closely with NPDES dischargers, we are including additional participants, such as the Irrigated Lands Regulatory Program and IEP, to ensure full representation of water quality monitoring within the Delta.

Modifying Monitoring Requirements

Regional Board staff, informed by stakeholder input, have been taking a hard look at the existing receiving water monitoring requirements for NPDES dischargers, including the location and frequency of monitoring and the constituents that are monitored. There appear to be numerous opportunities to leverage, combine, or alter the monitoring in order to provide better regional information. Staff from the planning, permitting, and enforcement sections are participating in these discussions. Regional Board staff recognize that coordination needs to happen internally and externally and are working to ensure required monitoring has a purpose and is relevant to continued protection of beneficial uses. There is general agreement that we are not utilizing all readily available information and doing so may lessen the monitoring requirements for particular constituents. Staff is exploring the possibility of adaptive monitoring based on records of compliance, sampling frequencies, and likelihood of exceedances. Further, it appears that there are opportunities to relocate or combine receiving water monitoring stations. These opportunities have the potential to free resources for the regional scale monitoring that is currently lacking.

What Questions Are We Trying to Answer

In its next phase of development, the RMP will strive for purposeful and efficient compliance monitoring from the local and regional perspectives. This will require identifying specific questions for the compliance monitoring to answer. In their interviews, the dischargers reiterated the principle that explicit management questions, a key component of the Delta RMP, are needed to establish effective monitoring designs. Such questions will guide revisions to receiving water monitoring and coordination with programs of the Department of Water Resources, Department of Fish and Game, and other agencies and entities that monitor water quality in the Delta.

Work to identify the management questions has begun. Through the pilot phase, the main question will likely be: "Are contaminants in the Delta at levels of potential concern?" (**Sidebar: Proposed Core Questions for the Delta RMP**). Answering this question is a priority for the Central Valley Water Board staff. An improved understanding of the spatial and temporal distribution of contaminants is necessary to answer this question. This information will identify areas and contaminants where additional regulations or controls are needed to protect beneficial uses.

Revised compliance monitoring requirements and clearly stated management questions will be the foundation for the long-term program. An initial monitoring plan will be developed through a workgroup process. Identifying discharges that are in close proximity and coordinating monitoring to address questions about localized cumulative impacts will test our regional monitoring concepts on a small scale and help to identify challenges as we broaden the reach. Additionally, these initial pilot projects will provide an opportunity to work with the data management system developed by the State Water Board and test its utility for compiling, analyzing, and reporting data.

While this next phase of RMP development is focused on programs under the direct regulatory control of the Central Valley Water Board, we recognize that answering many of the broad regional questions will require collaboration with other programs, such as the IEP.

Critical Steps

The goal of the Delta RMP is to provide comprehensive monitoring of contaminants in the Delta to ensure protection of beneficial uses. As we move forward in implementing small pilot projects, there are still critical conditions that must be met to ensure the long-term success of the Delta RMP. The currently envisioned pilot projects are focused on reorganization and coordination of monitoring to gather the information needed to answer specific questions. However, these improvements won't do much good unless the collected data are actually analyzed and synthesized into those answers. To date, we have not developed these systematic assessment capabilities. A successful Delta RMP will not only perform the monitoring that is needed, but also regularly compile, synthesize, and report the information. A successful RMP must identify and establish a trusted entity to compile and relate these assessments. Further, that entity will require stable funding to perform and publish these syntheses. The Pulse of the Delta is an example of the type of reporting that could be provided, but its production requires a substantial amount of time, expertise, and funding. Finding solutions to these challenges will fulfill the ultimate goals of the RMP over the long-term: generating, compiling, synthesizing, and regularly reporting information that managers need to protect the beneficial uses of this important ecosystem.

SIDEBARS

1. Better Data Comparability and Access With CEDEN

In an attempt to evaluate the role of contaminants in the Pelagic Organism Decline (POD), the State Water Resources Control Board (State Water Board) and the Central Valley Regional Water Quality Control Board (Regional Water Board) sponsored a review by U.C. Davis researchers of the available data (Johnson et al 2010). Their evaluation was impeded by the difficulty in integrating data of varying quality from multiple sources. As a result, a definitive conclusion could not be reached and the report recommended improvements in data management and integration in order to provide more consistent quality and easier access.

The State Water Board recognized the need to increase data access while also enhancing coordination among the various entities collecting water quality data. The State Water Board is now committed to making water quality data accessible to all interested parties. To this end, Water Board staff are coordinating with a variety of organizations and agencies to make data available via the California Environmental Data Exchange Network (CEDEN).

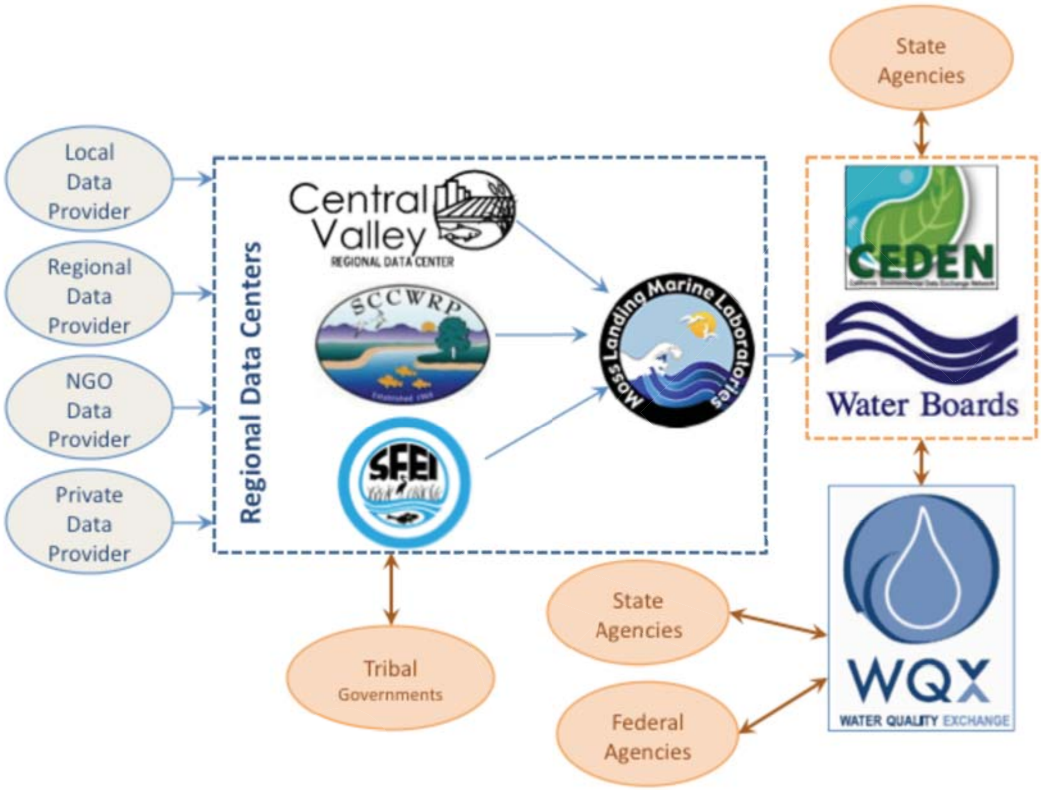
The cost of water quality monitoring in California has been estimated at a staggering $60 million annually. As the POD report illustrated, in the past it has been difficult, even cost-prohibitive, to access and combine this wealth of data to conduct comprehensive assessments of water quality condition. These assessments are needed to answer questions important to resource managers, the Legislature, and the public. In our current budget climate, when we are being asked to accomplish more with fewer resources, it is of great benefit to the Water Boards to invest in data comparability and access.

To ensure data quality and usability, the State Water Board developed a Minimum Quality Assurance (QA) and Data Reporting system. The system establishes guidelines and provides tools for QA and data reporting that are simple and easy to implement.

The Minimum QA System defines the minimum criteria for data and is based on standard quality control methods, processes, documentation, and reporting requirements that are already commonly in use. Data reports must include "Minimum Data Elements" to ensure that the data are usable and can be combined with other data in CEDEN.

Over the last year, the Water Board has made significant progress in amassing surface water quality data collected by a variety of government agencies and non-profit organizations. Data from Water Board programs, the U.S. Environmental Protection Agency, the Department of Water Resources, the U.S. Geological Survey, and other federal and state agencies will be available for download on the CEDEN website. Since data accepted into CEDEN has, as its foundation, a minimum set of data elements, users can evaluate the appropriateness of combining data sets for assessment purposes. CEDEN provides descriptive metadata for each dataset and establishes standard terms for characterizing individual data points.

CEDEN is a vehicle through which data comparability and integration can be achieved in California. It will do so through coordination with data providers and by providing a single point of access for ambient water quality data collected by the Water Board and other organizations.



The California Environmental Data Exchange Network (CEDEN) is a system for integrating and sharing data collected by many different participants. It is a growing statewide cooperative effort open to federal, state, county, and private organizations interested in sharing data. The purpose of CEDEN is to allow the exchange and integration of water and environmental data between groups and to make it accessible to the public. Local and private data providers work with and through the regional data centers. The regional data centers assist the data providers to ensure quality control and assurance. Additionally, the Water Boards have begun to build connections to other databases. The idea is that data available through other agency databases, like the U.S. Environmental Protection Agency's Water Quality Exchange (WQX), can be retrieved through a query in CEDEN and vice versa. The Water Boards are committed to continuing to build these connections to allow seamless retrieval of data

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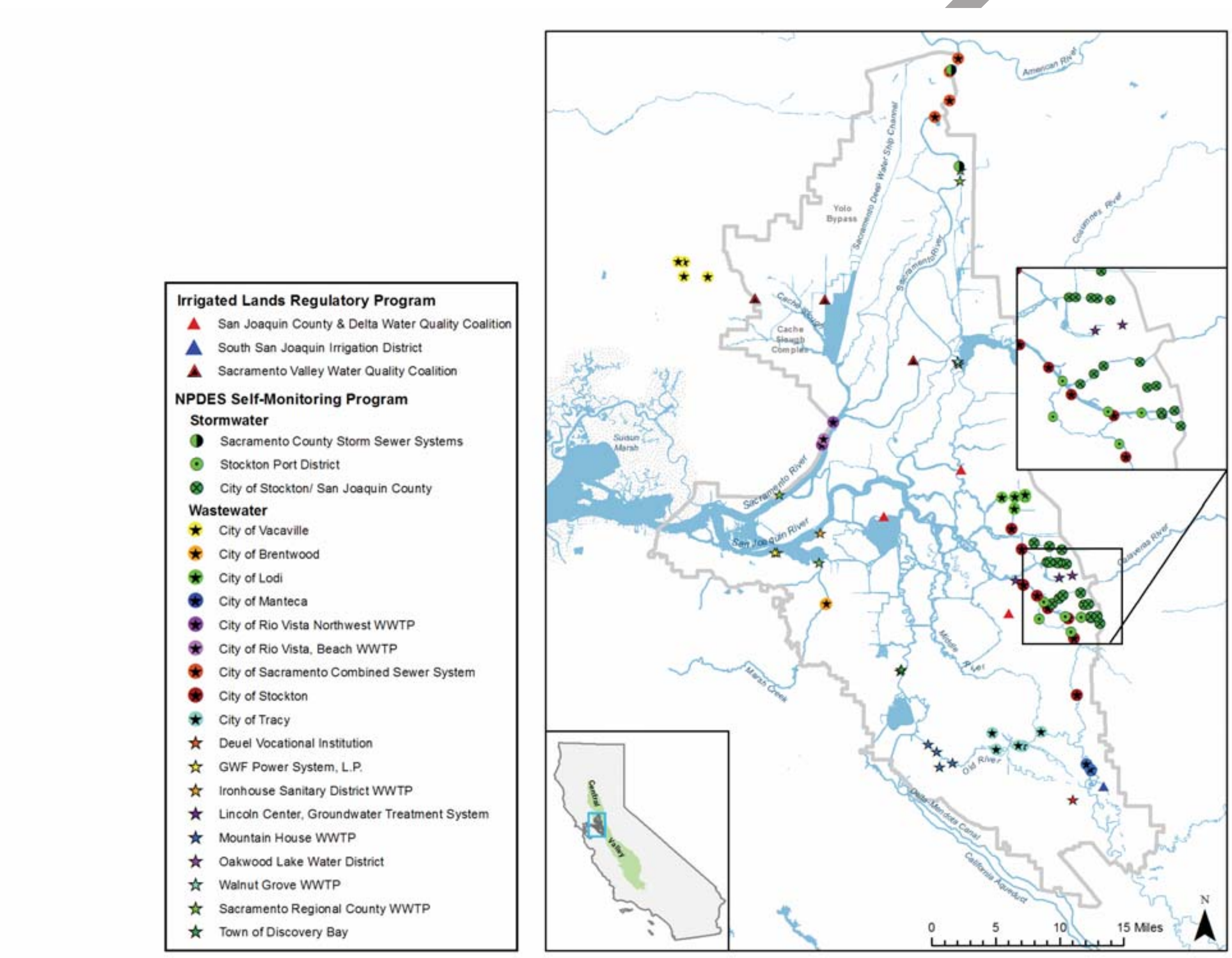
Illustrations

Figure 1. Compliance monitoring sites in the Delta



Footnote: WWTP = Wastewater Treatment Plant

b. USEPA Initiates Delta Stressor Investigation

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Highlights

- The U.S. Environmental Protection Agency (EPA) reviewed Clean Water Act (CWA) programs in the Bay Delta Estuary (Estuary) to evaluate success in protecting aquatic resources and to identify critical actions to accelerate restoration of water quality.
- EPA considered seven aquatic stressors in the review: ammonia, selenium, pesticides, contaminants of emerging concern, declining estuarine habitat, fragmented migratory corridors, and wetland loss.
- Public comments solicited as part of the review generally support protection of Bay Delta Estuary aquatic resources, though opinions diverge about which stressors are the most harmful and how best to restore and protect aquatic habitat.
- The EPA review suggests that CWA programs are not adequately protecting Bay Delta Estuary aquatic resources.
- After consideration of the public comments, EPA highlights six critical activities: 1) Modify the estuarine habitat standard in the "Bay-Delta Water Quality Control Plan," 2) advance regional monitoring and assessment programs in the Central Valley, 3) comprehensively identify Bay Delta Estuary impairments, 4) improve implementation of TMDLs, 5) provide relevant and timely water quality data to consider in national pesticide registration reviews, and 6) develop methylmercury controls in wetlands.

Achieving Water Quality Protection Goals

EPA began evaluating CWA programs' effectiveness in protecting Bay Delta Estuary aquatic resources by issuing an Advanced Notice of Proposed Rulemaking (ANPR) for

Water Quality Challenges in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Bay Delta Estuary) in February 2011. The ANPR was one of EPA's commitments in the December 2009 Interim Federal Action Plan (IFAP), which outlined actions and investments by EPA and five other federal agencies to help address ecological and water supply crises in the Bay Delta Estuary.

The ANPR:

1. Identifies the key water quality issues affecting Bay Delta aquatic resources and summarizes current research for each of these issues, including ammonia, selenium, pesticides, emerging contaminants and conditions restricting estuarine habitat, migratory corridors of anadromous fish (i.e., salinity, dissolved oxygen and temperature), and wetland losses;
2. Explains the status of regulatory efforts under the federal Clean Water Act and the State's clean water laws; and
3. Solicits public input on specific scientific and policy questions.

Focusing on the Fish Decline and Seven Associated Stressors

The long-term decline of native fisheries in the Bay Delta Estuary over several decades is dramatic and well-documented (see **Ecosystem Health Trends at a Glance**, page 30). After 2000, four open water fish species, including two species that were previously the most abundant in the Estuary (striped bass and threadfin shad), suffered nearly simultaneous, sharp population declines. Salmonid fish populations also show dramatic declines since the year 2004, resulting in the closing of commercial and sport fishing in 2008 and 2009.

Identifying the most harmful stressors to aquatic life in the Bay Delta Estuary is challenging. Currently, water quality data is collected by multiple agencies, with little standardization of monitoring procedures, data quality assurance, or presentation protocols, and often is not readily accessible. This makes regional assessments of water quality trends, identification of regional problems, and evaluation of solutions difficult and costly. Development of regional monitoring programs in the Delta and in the San Joaquin Basin is a high priority for EPA and the Central Valley Regional Water Quality Control Board.

EPA's assessment focuses on the most significant water quality stressors affecting fish in the Estuary. A substantial amount of research links these stressors to the pelagic organism decline (POD) and the subsequent decline of salmonid species. These stressors include contaminants (ammonia, selenium, pesticides, and contaminants of emerging concern) and habitat stressors (declining estuarine habitat, wetland loss, and fragmented migratory corridors). The assessment summarizes current knowledge as follows:

Contaminants

All Bay Delta Estuary waters are impaired due to many different contaminants.

Elevated **ammonia** levels are linked to changes at the base of the aquatic foodweb by suppressing algal growth and toxicity to invertebrates (see article on **Ammonia in the Delta** in The Pulse of the Delta 2011). Wastewater treatment plants (WWTPs) are the primary sources of **ammonia** to the Estuary.

Selenium is highly bioaccumulative and can be toxic to juvenile salmon, sturgeon, and waterfowl. The primary sources of selenium to the Estuary are selenium-rich soil and crude oil. Selenium is mobilized through agricultural return flows on the west side of the San Joaquin Valley. It is also discharged by refineries located in northern San Francisco Bay that process selenium-rich crude oil.

Organophosphate and pyrethroid **pesticides** are increasingly found in urban runoff and have been identified as a cause of aquatic toxicity in multiple investigations. Aquatic life in the Estuary can be exposed to multiple current-use **pesticides** for extended periods of time, with some pesticides causing acute and chronic toxicity. Pesticide sources include urban and agricultural runoff, WWTPs, and atmospheric deposition (see **Figure 1**).

Contaminants of emerging concern (CECs) are compounds such as pharmaceuticals and personal care products that may have significant negative effects on aquatic species. Numerous pharmaceuticals and personal care products are being evaluated for potential effects on aquatic life, such as developmental problems and skewed gender ratios. Sources of CECs include wastewater, urban and agricultural runoff, and animal husbandry.

Aquatic Habitat

The loss of **estuarine habitat** and the poor quality of remaining habitat is a primary driver of plummeting resident fish populations. The Estuary's freshwater-saltwater interface, or the "low salinity zone" (LSZ), contains the greatest abundance of many open water estuarine organisms. The LSZ is often referred to by its indicator measurement "X2" (see **Figure 2**) which is equal to the distance (in kilometers) from the Golden Gate to the 2 ppt isohaline, the location where the salinity of the water near the bottom is two parts per thousand (about 6% seawater).

Since 2000, the LSZ in fall months has been consistently upstream of Suisun and Honker Bays, reducing the area of LSZ habitat by 78%. As the LSZ moves eastward from Suisun Bay into the western Delta, its area shrinks and habitat quality for estuarine species is substantially degraded. The brackish tidal marsh habitats of Honker Bay, Suisun Bay, and Suisun Marsh offer more abundant food, cooler water, sufficient dissolved oxygen, turbidity, structural diversity, and protection from predators. By contrast, deep channels and armored banks characterize the western Delta, along with higher water temperatures, less food, and considerably more exposure to predators.

Prior to 2000, the location, size, and quality of the LSZ varied more from year to year, providing access in some years to high quality estuarine habitat in Suisun Bay. The LSZ during the fall months has been consistently located in the poor habitat of the western Delta in all water year types since the year 2000, until the very wet conditions of fall 2011.

Physical and chemical conditions in Delta waterways also **block migratory corridors** for fish on their journey from the watershed through the Estuary and contribute to declining populations of salmonid species. **Water quality barriers** include low dissolved oxygen, elevated temperature, and altered hydrology (**Figure 2**). Low dissolved oxygen conditions in the Stockton Deep Water Ship Channel, the lower San Joaquin River, and in Old and Middle Rivers can entirely block upstream migration of Chinook salmon to the San Joaquin River. Water temperatures in salmon streams of the San Joaquin basin can prevent migration and recruitment for salmonids and exceed EPA temperature thresholds for Chinook salmon. Dams and diversions modify natural hydrology by removing San Joaquin River water from the Delta and filling San Joaquin River channels with Sacramento River water. This modification erases the hydraulic connection and chemical cues adult salmon need to navigate from the ocean into San Joaquin River freshwater spawning sites.

Extensive **habitat destruction** of the Estuary's **marshes, sloughs, floodplain, wetlands, and riparian areas** (**Figure 3**) eliminated aquatic habitat that supported a great diversity of species. Remnants of high value habitat remain in the brackish tidal marsh and sloughs along the edge of Suisun Bay and Marsh, but these habitats have been eliminated from the western Delta. Seasonally flooded habitat supports rearing of migratory fishes, such as juvenile salmon, and spawning of estuarine fish such as splittail. However, 1100 miles of levees in the Delta separate active river channels from floodplains, effectively eliminating the majority of these habitats.

Large-scale tidal and freshwater wetland restoration is proposed on mercury-contaminated sites in the Delta, making it critical to minimize formation and transport of methylmercury. Mercury is transformed to methylmercury in low oxygen conditions that are present in wetlands. Methylmercury negatively affects aquatic dependent wildlife, commercial fishing, and public health. Mercury-contaminated soils create the potential for proposed wetland restoration sites to be a large source of methylmercury to the Bay Delta Estuary.

Evaluation of Changes to EPA Programs Based on Public Input

EPA requested comment on what the agency might do to respond to the Bay Delta Estuary ecological collapse. EPA received 55 comments, from a range of state, local, and federal government agencies, non-governmental organizations, businesses, and individuals. Some comments provided additional technical information. Comments generally supported protection of Bay Delta Estuary aquatic resources. Many comments related to the challenges in addressing cumulative and interactive effects of multiple stressors on aquatic resources. Many respondents encouraged pollution prevention as a less costly, more effective method of protecting aquatic resources and attaining water quality standards than removing pollutants from urban and agricultural runoff. Several stakeholders supported EPA's evaluation of CWA program efficacy, while other stakeholders expressed concerns about increased regulation. A comment summary and the original comment files are posted on the EPA website at www.epa.gov/region9/water/watershed/sfbay-delta.

EPA's Conclusions and Recommended Actions

EPA evaluated public comments, reviewed additional scientific information, and consulted with state and federal regulatory partners to determine how CWA programs can better protect aquatic resources in the Bay Delta Estuary. The conclusions of this work are as follows:

Are CWA Programs adequately protecting aquatic resources?

CWA programs are not adequately protecting aquatic resources in the Bay Delta Estuary. This conclusion is supported by the long-term decline and recent sharp drops in populations of estuarine species, combined with decades of elevated levels of contaminants.

Responding to the lack of adequate protection

EPA, the Water Boards, and other partners are actively working toward achieving water quality conditions that support and protect aquatic resources. The State Water Board plans to address the quantity and quality of estuarine habitat by reviewing and changing Delta outflow objectives to better protect fish and invertebrate populations. The Board began this review in 2012 and plans to conclude in 2014. The State Water Board is also reevaluating San Joaquin River Flow objectives, with the goal of restoring successful migration of salmonids.

The Water Boards moved to controlling the largest known source of ammonia to the Bay Delta Estuary in December 2011, when they added ammonia removal to the Sacramento Regional WWTP CWA discharge permit. The California Department of Pesticide Regulation recently proposed pesticide regulations for protecting surface waters from urban pyrethroid applications and the Water Boards are implementing and developing Total Maximum Daily Load Programs and numeric objectives for organophosphate, organochlorine, pyrethroid, and other pesticides known to impact aquatic resources.

Nationally, EPA will propose updates to ammonia and selenium guidance criteria for freshwater aquatic life. The Total Ammonia Nitrogen Aquatic Life Guidance Criteria were released in draft form in 2009 and provide stronger protection of freshwater invertebrates. Site-specific, numeric selenium criteria are being developed by EPA Region 9 and partners to protect Bay Delta aquatic and terrestrial species while EPA updates national selenium guidance criteria for freshwater aquatic life. EPA is also developing the "Common Effects Methodology," a consistent approach under the Federal Insecticide Rodenticide and Fungicide Act (FIFRA) and CWA for estimating the effects of pesticides on aquatic life.

What critical actions should EPA and others take to protect aquatic resources?

EPA's review highlights six critical activities:

1. Modify the estuarine habitat water quality standard. The State Water Board recently initiated review of the estuarine habitat protection standard in the "Bay-Delta Water Quality Control Plan" (WQCP), which requires EPA review and approval. EPA provided technical support for updating the WQCP by synthesizing findings from a March 2012 workshop that convened scientists to discuss aquatic resource responses to different locations of the low salinity zone.

2. Advance progress in regional water quality monitoring and assessment programs. EPA will continue to provide financial and technical support as the Water Boards establish Regional Monitoring Programs in the Delta and Central Valley that integrate monitoring and assessment across agencies and activities. In February 2012, EPA gathered stakeholders for the "Who's Watching the San Joaquin River" forum to identify shared interests in water quality monitoring and assessment in the San Joaquin Valley.

3. Identify all designated use impairments. The CWA requires states to identify as "impaired" those waterways that do not meet water quality standards. Standards include designated uses, water quality criteria, and an anti-degradation requirement. Water quality standards are not attained, if any one of the three components of standards is not supported by water quality. There is substantial documentation that water quality in the Delta does not support aquatic life designated uses, including estuarine habitat; rare, threatened or endangered species; and migration of aquatic organisms. We recommend that the Water Boards identify the cause of these aquatic habitat losses and list waterways not supporting these designated uses as impaired in the next CWA 303(d)/305(b) report.

4. Improve TMDL development and implementation. EPA will support the Central Valley and San Francisco Bay Water Boards in developing and implementing TMDLs. We will identify outstanding and high priority actions in adopted TMDLs for targeted funding and add more accountability and transparency to documenting TMDL progress. Twenty-seven TMDLs have been approved in the Bay Delta Estuary watershed and fifteen others are under development.

5. Focus on pesticide pollution prevention. Some water pollution problems are caused by application of pesticides that are legally registered under FIFRA. EPA is committed to including California pesticide water quality data in the national pesticide registration review process to mitigate these problems in the future.

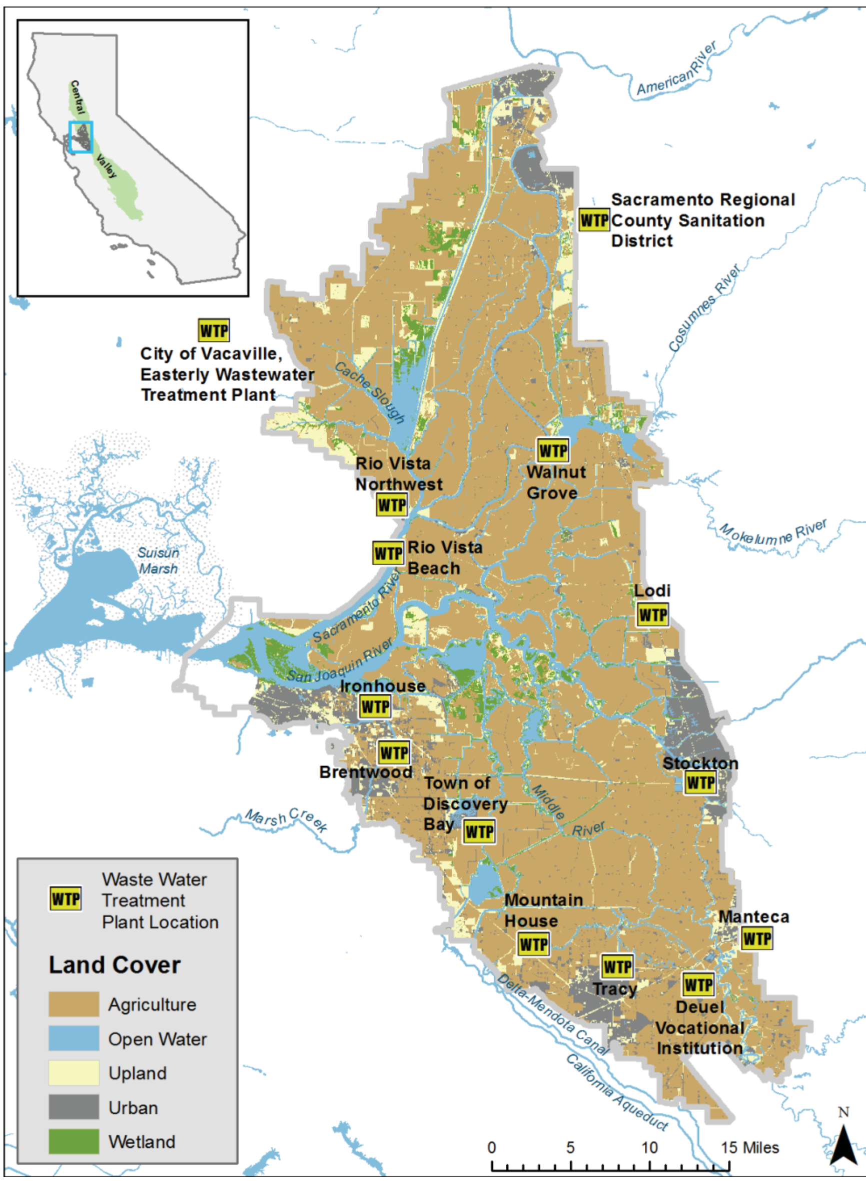
6. Develop methylmercury control methods. EPA is supporting the Delta Mercury and Methylmercury TMDL by funding projects that will identify methods for minimizing the formation and transport of methylmercury, which are needed for protecting multiple designated uses. EPA is contributing to the development of methods for methylmercury and carbon sequestration by the U.S. Geological Survey and to the Dutch Slough restoration project by the California Department of Water Resources (DWR), which includes management of methylmercury formation and transport.

These critical actions are designed to complement ongoing water quality work and are essential for improving water quality for the benefit of aquatic resources in the Estuary. Together, the completion of ongoing water quality work and the critical actions outlined above will support our goal to accelerate restoration and protection of aquatic resources in the Bay Delta Estuary.

Illustrations

Figure 1.

Contaminant sources include urban and agricultural runoff, wastewater treatment plants, and atmospheric deposition. The map shows land uses and locations of wastewater treatment plants in the Delta



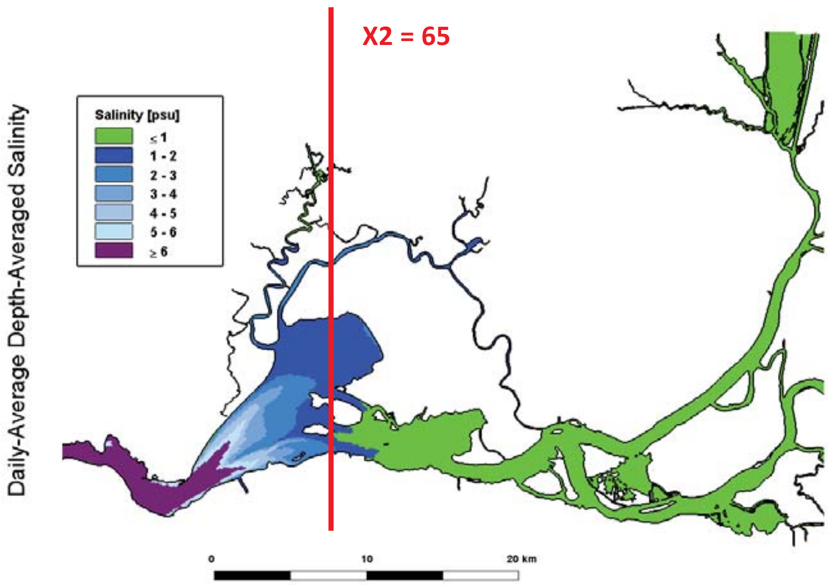
Footnote: Data source: Delta Vegetation and Land Use. 2007. Aerial Information Systems, Inc., for the California Department of Fish and Game, Vegetation Classification and Mapping Program.

Figure 2.

The Estuary's brackish water, or the "low salinity zone" (LSZ), contains the greatest abundance of many open water estuarine organisms. The LSZ is often referred to by its indicator measurement "X2", which is equal to the distance (in kilometers) from the Golden Gate to the 2 ppt isohaline, the location where the salinity of the water near the bottom is two parts per thousand (about 6% seawater). Since 2000, the LSZ during the fall months has been consistently located in the poor habitat of the western Delta in all water year types. Prior to 2000, the location of the low salinity zone during the fall varied between the western Delta and Suisun Bay, providing access in some years to high quality estuarine habitat in Suisun Bay. After 2000, the low salinity zone in the fall has been consistently further upstream in the poorer habitat of the western Delta, until the very wet conditions of fall 2011 extended it again further downstream. The figures illustrate the relationship between the LSZ and the X2 indicator: (a) When X2 = 65 km (downstream of Roe Island), the low salinity zone (in shades of blue from 1-6 ppt) stretches across the broadest regions of Suisun Bay adjacent to Suisun Marsh and covers 7704 hectares. (b) When X2 = 74 km (at Chipps Island), the low salinity zone increases 19% to 9140 hectares, but it is less optimal with higher salinities in Grizzly Bay and the lowest salinities found only in smallish Honker Bay. (c) When X2 = 81 km (at the confluence of the Sacramento and San Joaquin rivers), the low salinity zone is compressed into the relatively deep river channels of the Western Delta, where the areal extent of estuarine habitat drops 36% to 4914 hectares. (d) When X2 = 85 km, the isohaline approaches Antioch, and all connections to Suisun Bay and Marsh are lost. A relatively high salinity zone moves into Suisun, Grizzly, and Honker bays, and the areal extent of estuarine habitat drops to 4262 hectares.

Footnote: Maps are from Dr. Michael MacWilliams (Delta Modeling Associates, Inc.) and were generated using the UnTRIM San Francisco Bay-Delta model.

(a)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Daily-Average Depth-Averaged Salinity
Salinity [psu]
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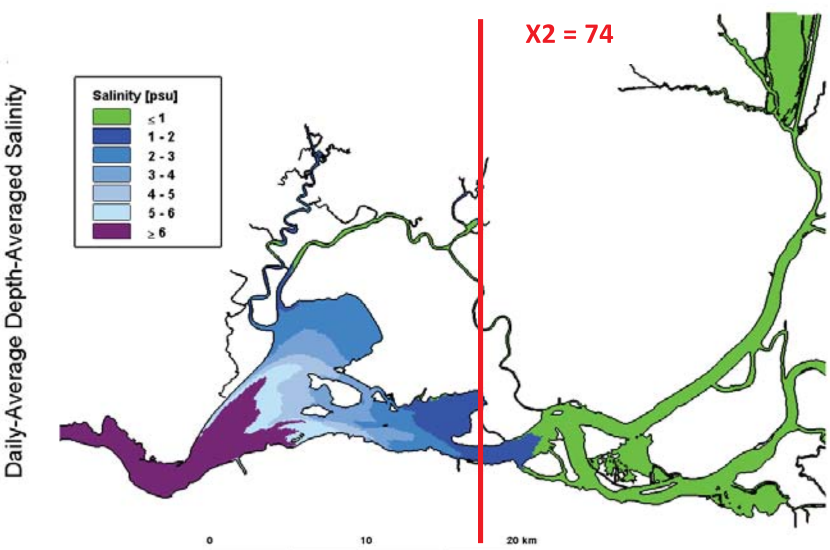
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
0
10
20 km

(b)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Salinity [psu]
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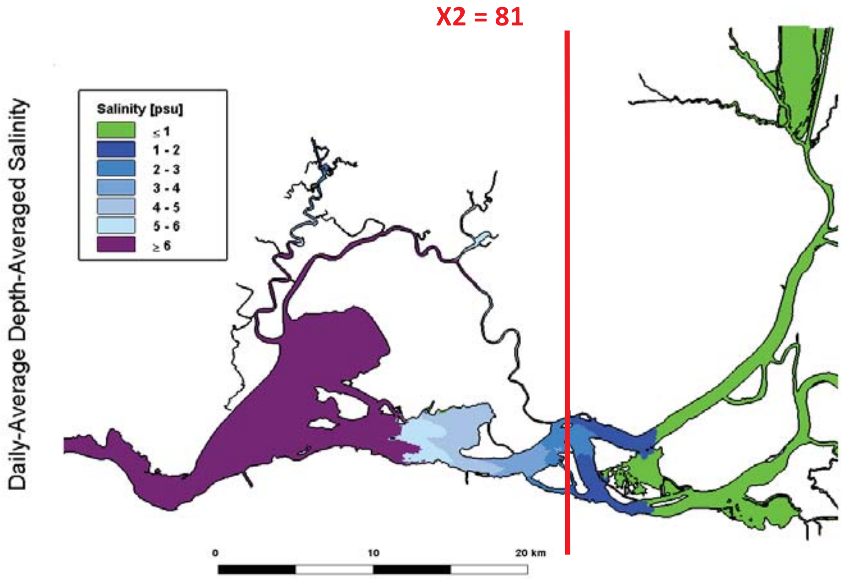
4 - 5
5 - 6
≥ 6
0
10
20 km

(c)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Daily-Average Depth-Averaged Salinity
Salinity [psu]
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4 - 5
5 - 6
≥ 6
0
10
20 km

(d)

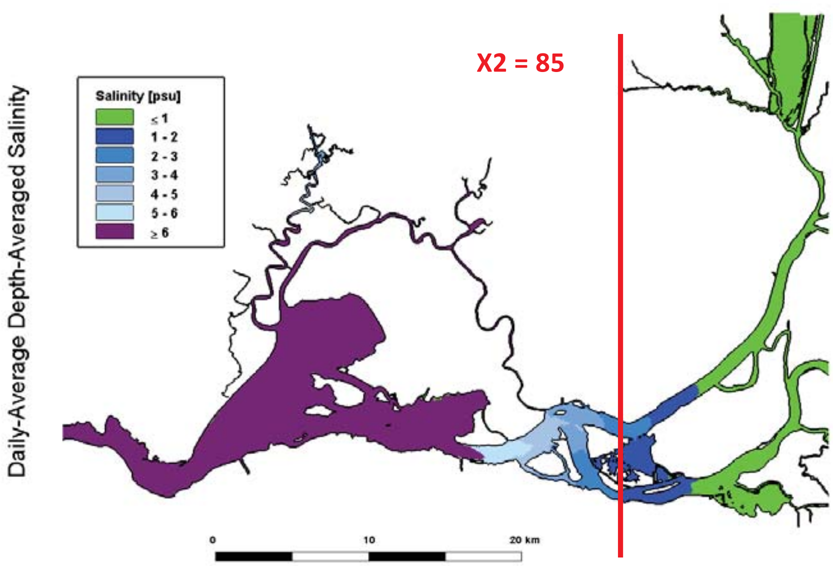
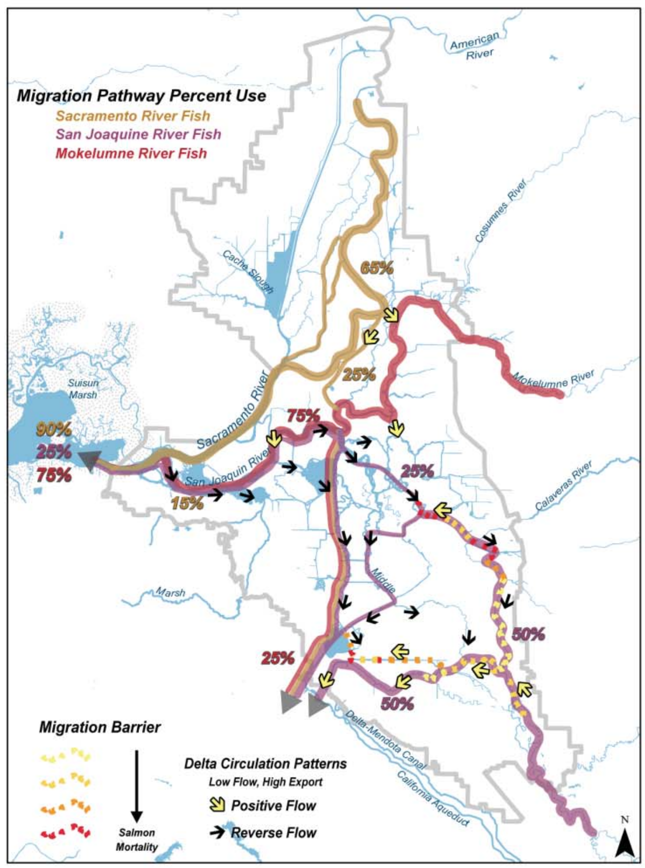

X2 = 85
Daily-Average Depth-Averaged Salinity
Salinity [psu]
≤ 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
0
10
20 km

Figure 3.

Low dissolved oxygen, high water temperature, and changed flow patterns in the Delta act as barriers to the passage of migratory fish on their journey through the Estuary and contribute to declining salmon populations. The map shows the main Delta migration corridors for Central Valley Chinook salmon, in relation to a) Delta water circulation patterns under low flow, high export conditions and b) survival of outmigrating juvenile salmon from the San Joaquin River. Low dissolved oxygen conditions in the Stockton Deep Water Ship Channel, the lower San Joaquin River, and in Old and Middle Rivers can entirely block upstream migration of Chinook salmon to the San Joaquin River. Dams and diversions modify natural hydrology by removing San Joaquin River water from the Delta and filling San Joaquin River channels with Sacramento River water. These modifications erase the hydraulic connection and chemical cues adult salmon need to navigate from the ocean into San Joaquin River freshwater spawning sites.



Footnote: Data sources: 1. California Urban Water Agencies. 1993. The Delta. 2. San Joaquin River Group Authority. 2010. 2010 Annual Technical Report. URL http://www.sjrg.org/technicalreport/2010/2010_05.pdf. 3.

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USEPA. 2011. Water quality challenges in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. Unabridged Advanced Notice of Proposed Rulemaking. URL http://www.epa.gov/region9/water/watershed/sfbay-delta/pdf/BayDeltaANPR-fr_unabridged.pdf

c. Protecting the Estuary from the Harmful Effects of Nutrient Enrichment: The Numeric Nutrient Endpoint Framework

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David Senn, San Francisco Estuary Institute/Aquatic Science Center

Highlights

- ⇨ The Bay-Delta has long been recognized as a nutrient-enriched estuary and it appears that its historic resilience to the harmful effects of nutrient enrichment is weakening.
- ⇨ The State is establishing nutrient water quality objectives as part of a holistic approach to managing nutrients in State waters.
- ⇨ The typical methods used to set water quality objectives, based on thresholds for concentrations in water, do not apply well to nutrients, so an alternative approach is needed.
- ⇨ The State's proposed approach to managing nutrients - Nutrient Numeric Endpoints - consists of two components: 1) an "assessment framework", which establishes a suite of numeric endpoints for indicators of an estuary's response to nutrients (e.g., algal biomass, dissolved oxygen) and 2) the use of models that link the response indicators with nutrient inputs.
- ⇨ Development of NNE for San Francisco Bay, and ultimately the Delta, will proceed by choosing indicators, establishing endpoints, developing nutrient load-response models, and assessing estuary condition through monitoring.

⇨ Successful nutrient management requires coordination of monitoring and research in the Bay and the Delta.

Losing Resilience?

The San Francisco Bay-Delta has long been recognized as an estuary with relatively high nutrient loads and concentrations, a result of treated wastewater discharge and riverine inputs dominated by agriculture and urban land uses (Smith and Hollibaugh 2006). For example, for its size, San Francisco Bay receives loads of nitrogen and phosphorus comparable to or greater than Chesapeake Bay, an estuary well known as being nutrient-enriched. Nonetheless, the abundance (biomass) of phytoplankton, the microscopic algae that are the basis for the food web, is substantially lower in San Francisco Bay than would be expected in an estuary with such high nutrient enrichment. Studies suggest that phytoplankton abundance in the Bay is limited by a combination of factors, including strong tidal mixing of the water column, short water residence times, light limitation due to high turbidity, and extensive grazing by clams. Over the past two decades, the Bay has not suffered from the typical symptoms of nutrient overenrichment, such as oxygen depletion or high algal biomass. In fact, primary productivity (a measure of algae and aquatic plant growth) in the Bay is considered to be very low (**Figure 1**). Therefore, regulators and managers have not previously prioritized reducing inputs of nitrogen and phosphorus to San Francisco Bay.

However, there is a growing body of evidence that suggests the historic resilience of the Bay to the harmful effects of nutrient enrichment is weakening. Since the late 1990s, regions of the Bay, from Suisun to South Bay, have experienced significant increases in phytoplankton biomass (30- 105%) and significant declines in dissolved oxygen (Cloern et al. 2007, 2010; **Figure 2**). Increased frequency of blooms of the toxin-producing cyanobacteria *Microcystis aeruginosa* in the North Bay (San Pablo and Suisun bays) and in the Delta further signal changes in the Estuary (**Figure 3**). In other areas of the Delta, increased nuisance floating and rooted submerged aquatic vegetation, such as water hyacinth (*Eichhornia crassipes*) and the invasive Brazilian waterweed (*Egeria densa*), is clogging waterways and industrial water intake pipes and now consumes over 60% of the California Department of Boating and Waterways aquatic pest control budget (CDBW Website).

The mechanisms underlying the decreased resilience are complex and not uniform throughout the Bay-Delta Estuary. For example, Cloern et al. (2010) demonstrated that increasing chlorophyll a (a measure of phytoplankton biomass) in the South Bay was linked to climate-driven increases in the populations of fish, crabs, and shrimp that feed on phytoplankton-grazing bivalves. Productivity in Suisun Bay and in the Delta may be controlled by different factors than in the South Bay. Dugdale et al. (2007) argue that elevated levels of ammonium in surface waters actually limit phytoplankton production in Suisun Bay and the lower Sacramento River. Lehman et al. (2008) found that flow and temperature exert major controls on the occurrence of *Microcystis* blooms in the Delta. The complexity of mechanisms controlling the response of the Estuary to nutrient loading highlights the importance of continued monitoring, research, and synthesis of science to support nutrient management.

The Challenge of Establishing Nutrient Objectives

Water quality objectives (WQO) are regulatory tools used to establish levels of pollutants (e.g. nutrients) that are protective of a waterbody's beneficial uses.

Setting water quality objectives for nutrients is scientifically challenging. Nutrients are required to support life, but assessing how much is "too much" is not straightforward. The typical approaches used to set water quality objectives (WQOs) for toxic pollutants do not apply, in part because adverse effects of nutrient over-enrichment occur at concentrations far below recognized toxicity thresholds. In addition, typical approaches to setting WQOs focus on ambient nutrient concentrations, rather than loads, to the waterbody. Total nutrient load to an estuary is often a better predictor of productivity than ambient surface water concentration because it integrates total exposure to nutrients over time, whereas concentration only provides a snapshot of available nutrients at a given point in time.

For California estuaries, a water quality objective based on a one-size-fits-all nutrient concentration is not appropriate. Estuaries are highly variable in how they respond to nutrient concentrations due to site-specific differences in, for example, in light availability, salinity, freshwater flows, and tidal mixing (NRC 2001). This combination of "co-factors" results in differences in how nutrients cycle within an estuary. A recent synthesis by Cloern and Dugdale (2010) has shown that ambient nutrient concentrations do not correlate with measures of primary productivity in San Francisco Bay, in part because of important co-factors that override simple nutrient limitation of primary production. Therefore, an alternative approach is needed.

One means of setting nutrient objectives that is suitable for estuaries is the cause-effect approach. The cause-effect approach, typically used in the process of setting Total Maximum Daily Loads (TMDLs) for waterbodies, involves setting numeric endpoints for indicators of estuary response to nutrient overenrichment. Response indicators can generally be placed in three main categories: 1) primary producers, 2) water and sediment chemistry, and 3) consumers (**Sidebar: Conceptual Model for Selection of Indicators**). The numeric endpoints for these response indicators are then mechanistically modeled to determine appropriate nutrient loads, incorporating important co-factors controlling response, such as flow, tidal mixing, or grazing by consumers. The advantage of the cause-effect approach is that the resulting response indicators are linked strongly to beneficial uses (**Sidebar: Eutrophication Effects on Estuaries**).

The Nutrient Numeric Endpoint Framework

State Water Board staff is proposing the cause-effect approach as the principal means to establish nutrient water quality objectives for California waterbodies. Their approach involves creating numeric guidance that will be used to translate a narrative nutrient water quality objective into numeric values. That guidance, referred to as "Nutrient Numeric Endpoint (NNE) framework," consists of two components: 1) an "assessment framework", which establishes a suite of numeric endpoints based on response indicators (for example, algal biomass, dissolved oxygen) and 2) the use of mechanistic models that link response indicator numeric endpoints with nutrient loads and other factors.

The NNE framework has already been developed for California streams and lakes (TetraTech 2006) and is now under development for estuaries. Numeric endpoints were established for benthic algal biomass in streams and phytoplankton biomass in lakes. Endpoints were also established for water chemistry indicators such as dissolved oxygen and pH. Models were developed to link these numeric endpoints to waterbody-specific nutrient load targets. These models, which in the case of freshwater streams and lakes are simplified spreadsheet versions of dynamic computer simulation models, allow the user to account for the site-specific co-factors that modify the response to available nutrients. These spreadsheet models are offered as scoping tools; if increased precision is required, stakeholders are encouraged to pursue dynamic simulation models or alternative peer-reviewed approaches to establish site-specific nutrient targets.

Developing the NNE Framework for San Francisco Bay

The NNE framework is currently under development for all California estuaries. This process began through the selection of response indicators applicable to all estuaries and a review of science supporting the selection of numeric endpoints for each indicator (Sutula 2011). Because the Bay-Delta Estuary is the largest of California's estuaries and a complex ecosystem that represents more than one-third of all estuarine habitat statewide, it was decided that it merits its own NNE framework. An extensive literature review was completed, focused on San Francisco Bay. The review identified candidate NNE indicators, summarized the status of symptoms of eutrophication in San Francisco Bay using these indicators, reviewed available nutrient loading data, and identified key data gaps and next steps (McKee et al. 2011). A separate review and process would be appropriate for the Delta at some point in the future.

The literature review and data gaps analysis resulted in four main recommendations for moving forward with the development of the NNE in San Francisco Bay: 1) finalize response indicator selection and designate numeric endpoints, 2) develop load-response models, 3) conduct monitoring to support load-response model development and to support implementation of the NNE, and 4) coordinate nutrient management and monitoring activities with the Delta.

Select Response Indicators and Numeric Endpoints

Ideally, NNE response indicators should be: 1) strongly linked to Bay-Delta beneficial uses, 2) quantitatively coupled to nutrient loads and other co-factors using predictive models, 3) scientifically well-vetted and cost-effective to measure, and 4) reliably used to assess eutrophication or other adverse effects of nutrients (i.e., good signal/noise ratio). McKee et al. (2011) used these four characteristics as evaluation criteria to propose response indicators for San Francisco Bay.

Appropriate response indicators vary by habitat type in an estuary. **Figure 4** shows the four main habitat types found in all estuaries: 1) unvegetated subtidal, 2) seagrass and brackish submerged aquatic vegetation (SAV), 3) intertidal flats, and 4) marsh. Thus, the appropriate indicators can sometimes be different among estuaries, or even within an estuary.

Because the Bay is dominated by subtidal habitat, with only a minor amount of seagrass and SAV, the priority indicators recommended by McKee et al. (2011) are heavily weighted toward unvegetated subtidal habitat: dissolved oxygen and phytoplankton (e.g., biomass, productivity, assemblage, cyanobacterial abundance, and toxin concentration).

Other indicators, such as macroalgal biomass and cover, may be appropriate in the Bay's managed ponds or tidal sloughs with sluggish circulation. Appropriate indicators for the Delta may overlap with those for the Bay (e.g. dissolved oxygen, phytoplankton), but could also include some unique indicators such as the abundance of floating macroalgae or water hyacinth (**Figure 3**).

Ammonium was considered as a potential indicator for the Bay, due to its hypothesized role in limiting phytoplankton production (Dugdale et al. 2007; Jabusch 2010). However, at this time ammonium has not been designated as a primary indicator because the importance of ammonium inhibition of diatom blooms relative to other factors controlling primary productivity Bay-wide is not well understood. Additional review and synthesis on this topic are recommended, pending completion of currently funded studies.

For the Bay, the next steps in the process include determining how to set numeric endpoints for the response indicators and to assess whether beneficial uses are met. Because subtidal habitat dominates, development of an assessment framework for this habitat type is a priority. Two primary indicator groups for this habitat type include: 1) dissolved oxygen and 2) phytoplankton (**Sidebar: Conceptual Model for Selection of Indicators).**

Dissolved oxygen objectives already exist for the Bay. It may be possible that site-specific objectives for some subhabitats are needed and a proposal to review science supporting revision of dissolved oxygen objectives for the Bay is being considered by the San Francisco Bay Water Board.

The process for developing NNE for phytoplankton begins with synthesizing existing data and engaging local scientific experts. Scientists must provide advice on what are the most appropriate attributes of phytoplankton to use (e.g., biomass, productivity, and taxonomic composition), how to account for spatial and temporal variability in phytoplankton when making an assessment, as well as summarizing information on how the magnitude, duration, and frequency of phytoplankton blooms relates to beneficial uses. This information is synthesized, into multiple categories of "condition", using best professional judgment. The Water Boards, through a public process, would make a final decision on the numeric endpoints.

A Major Emphasis on Load-Response Models

An important component of implementing the NNE framework in San Francisco Bay is the development of models that can simulate the ecological response to nutrients and other important co-factors. Several types of models need to be developed, fitting into two general categories: 1) loading models, which estimate the load of nutrients reaching the Bay and where they originate, and 2) Bay water quality models, which simulate the ecosystem response to nutrient loads and other factors. Loading models can give managers insight on how they might best control nutrient loads. Water quality models aim to predict a system's response to a given load and may reveal ways to alter the response if necessary.

Development of load-response models should begin with conceptual models. These conceptual models need to be region-specific, to account for spatial variability of co-factors within the Bay. The Regional Monitoring Program for Water Quality in the San Francisco Estuary (Bay RMP) has funded the development of these conceptual models for the Bay in 2012.

Another essential element in the development of load-response models is reliable data on the sources and pathways of nutrient loads to the Bay-Delta. Estimates of nutrient loads to the Bay from external sources and pathways are generally outdated and uncertain. Accurate estimates of nutrient loads and how they vary over space and time are needed. It is recommended that a focus be placed on better characterizing the magnitudes of nutrient loads from all wastewater and stormwater to the Bay-Delta watershed, since these appear to be considerably larger sources of nutrient loads than direct atmospheric deposition and groundwater, which combined likely constitute less than 10% of the total loads to the Bay. The Bay RMP has also funded an initial study in 2012-2013 to assess nutrient loads based on existing data and identify major data gaps and uncertainties.

Mechanistic load-response models can vary from simple box models to dynamic simulation models (**Sidebar: Load-Response Models**). Dynamic simulation models are the most complex type of model and promise the most accurate predictions of ecological response to nutrient loads within San Francisco Bay. They require considerable data and knowledge about nutrient dynamics, co-factors (including complex hydrodynamics), and indicator responses in the system. It will take several years and a large investment in research and monitoring to develop such models. An important step towards the development of these dynamic simulation models is the testing out of key concepts and assumptions in smaller, simpler box models. These simple box models can be used to synthesize empirical data to develop coarse nutrient budgets for the Bay, estimate the sensitivity of the Bay's response to key co-factors, and identify critical data gaps. A review of existing models and their applications should be undertaken, to understand which existing tools might be useful.

Ultimately, if NNE are to be developed for the Delta, models must be developed or extended from the Bay into the Delta. Considerable effort has already gone into water quality modeling and synthesis of science for the Delta, so consideration of what may be appropriate for the Bay should consider models already developed for the Delta.

Nutrient Assessments As an Opportunity to Involve Delta Stakeholders

A key need is a monitoring program to support regular NNE assessments of San Francisco Bay and to develop and validate nutrient load-response models. This increased need for Bay-wide monitoring exists at a time when the availability of resources to continue assessing the Bay's condition is uncertain.

Since 1969, USGS has supported one of the world's premier water-quality sampling programs in the Bay. This program collects monthly samples between the South Bay and the lower Sacramento River to measure nutrients, dissolved oxygen, chlorophyll a, and associated parameters. Despite the USGS's long-standing investment in water quality sampling in the Bay, there is no guarantee that this program will continue to be supported. The USGS data, along with sampling conducted by the IEP, provide coverage for the entire San Francisco Bay–Delta system. Because the IEP's long-term monitoring extends into the Bay and covers many indicators that are relevant to the NNE, a nutrient monitoring program for the Bay should consider how to best leverage resources with the IEP. Evaluation of how to assess nutrient sources and pathways from the Delta to San Francisco Bay is also an area of clear nexus for discussion and coordination.

Major Strides Towards A San Francisco Bay Nutrient Strategy

The San Francisco Bay nutrient strategy will lay out the steps to develop the necessary scientific understanding to support informed decisions about managing nutrient loads and maintaining beneficial uses within the Bay. The nutrient strategy will focus on informing upcoming management decisions related to nutrients and eutrophication. The strategy will prioritize work elements, identify sources of funding for those elements, and ensure efficient use of the available resources. The San Francisco Bay Water Board is leading the development of this strategy, working collaboratively with stakeholders and scientists, to identify the technical studies required to support decisions regarding nutrient management.

SIDEBARS

1. Eutrophication

Nutrients, such as nitrogen and phosphorus, are naturally occurring chemicals that plants and animals need to grow and survive. When too many nutrients make their way into local rivers, streams and estuaries, they can create an overproduction of algae and aquatic plants, in a process known as "eutrophication." Eutrophication produces conditions that are harmful for fish, crabs, oysters, and other underwater life. An overproduction of algae can block light, clog gills, smother benthic habitats, and consume dissolved oxygen (see **Effects of Eutrophication on Estuaries**). Some of the types of algae that dominate can also produce harmful toxins. When eutrophication affects aquatic life at the base of the food web, then it can change or remove important food sources for fish, birds, and other organisms higher on the food web, effecting our local economy and tourism.

Nutrients have always been a part of our lakes, streams and estuaries and support the critical biological cycles that we rely on for life on earth, but not at the excessive levels found today. Natural sources of nutrients include soil, plant material, animal waste, the atmosphere, and even the ocean, when cooler nutrient-rich bottom ocean waters rise or are "upwelled" to the surface and transported into an estuary by tidal currents. Prior to significant human activity, most nutrients were absorbed or held in place by natural forest and wetland vegetation. As natural lands were replaced by farms and cities, nutrient pollution has greatly increased. In the Chesapeake Bay, regulators have used the analogy that the Bay has become "obese" from nutrient overenrichment, much like it occurs in humans when we eat too much of a good thing. Restoration of Chesapeake Bay requires a "pollution diet", reducing the major sources of nutrients in the water- and airshed.

In general, excess nutrients reach the Bay-Delta from three major sources: wastewater discharges, runoff from urban and agricultural land, and air pollution. Wastewater plants release treated water — often still containing large amounts of nutrients —to local streams and rivers or directly to the open water of the Estuary. Nutrients that run off the land and into the rivers— including farmland and urban and suburban areas — come from a number of sources, including fertilizers, septic systems, boat discharges, and farm animal manure. Air pollution from vehicles, industries, gas-powered lawn tools, and other emitting sources also contribute nutrients to aquatic habitats.

Though it is recognized as nutrient- enriched, at this point the Bay-Delta Estuary is not considered to be "obese;" if anything, it could be considered as "starved" of certain type algae thought to support a healthy Delta-Suisun Bay foodweb. An important component of a nutrient management strategy will be conducting scientific studies to understand what factors contribute most to controlling primary productivity in the Estuary, and determine what levels and types of nutrients best support aquatic life.

2. Effects of Eutrophication on Estuaries

Eutrophication has a variety of negative effects on estuary beneficial uses and ecosystem services:

- Changes in the abundance and composition of primary producers (i.e., algae), which are the base of the food web and support all aquatic life.
- Decreased biodiversity, with reductions and, in some cases, local extinction of rare, threatened, and endangered species.
- Toxin producing algal blooms that may harm people, dogs, and aquatic life.
- Increased frequency of low-oxygen "dead zones" in water and sediments. Hypoxia is the number one cause of fish kills and can also have chronic effects on aquatic life, affecting survival, growth, and reproduction.
- Increased production of bacteria, including pathogens, resulting in poor water quality and increased frequency of waterborne diseases.
- Clogging of navigable waterways and industrial and municipal intake pipes with macroalgae and other floating or submerged aquatic vegetation.
- Shading or smothering of seagrass, shellfish beds, and other important habitats.
- Changes in nutrient cycling that can further worsen the symptoms of eutrophication. For example, sediments of eutrophic water bodies tend to release nutrients back to the water at a faster rate, which increases internal nutrient loads. Eutrophic water bodies also lose their capacity for denitrification, a process carried out by microorganisms that converts nitrate to nitrogen gas, which subsequently becomes lost to the atmosphere.
- Poor aesthetics and odors from decomposing algae and plants and increasing sulfide production.
- Subsequent decrease and changes in community structure of invertebrates, birds, and fishes, and in some cases, collapse of fisheries.

Together, these adverse effects impair estuary beneficial uses. Affected uses include recreation, habitat quality, aquatic life, fisheries, navigation, drinking water, and industrial use.

3. Conceptual Model for Selection of Indicators: a Cause-Effect Approach

The Nutrient Numeric Endpoint (NNE) framework relies on a cause-effect approach to model the relationships between nutrient loads, important co-factors, and an estuary's response. An estuary's ecosystem response to increased nutrient loads can be described as a cascade of change:

1. *Changes to aquatic primary producers.* Examples: increased biomass and productivity accompanied by changes in the relative species composition of the algae and aquatic plants

may lead to

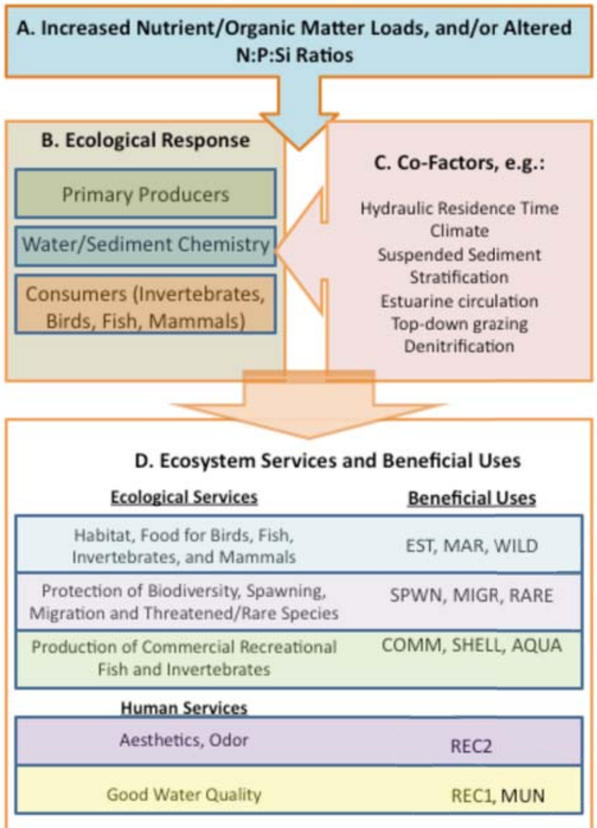
2. *Changes in water and sediment biogeochemistry*. Examples: declines of dissolved oxygen, increase in the water pH, and occurrence of toxic metabolites such as algal toxins and sulfide

may lead to

3. *Changes to the community structure*. Examples: changes observed in secondary (invertebrates) and tertiary consumers (fish, birds, mammals).

This cascade of change has a direct effect on the ecosystem services and beneficial uses an estuary provides (see **Effects of Eutrophication on Estuaries**). These three types of change can be used to organize possible indicators for eutrophication.

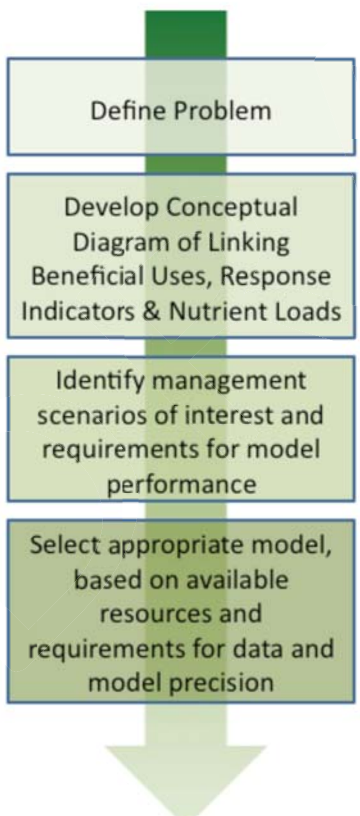
The following diagram represents a conceptual framework of the linkage between nutrient loading (A), ecological response (B), co-factors modulating response (C), and altered ecological services and beneficial uses (D). Ecological response indicators are selected because they provide a closer linkage to beneficial uses and integrate the effects of co-factors.



Footnote: Conceptual framework showing the linkage of (A) nutrient loading, (B) ecological response (C) co-factors modulating the ecological response, and (D) altered ecological services and beneficial uses (D). The ecological response (B) includes altered primary producer abundance and species composition, sediment and water biogeochemistry, and secondary & tertiary consumer abundance and species composition. From Sutula (2011).

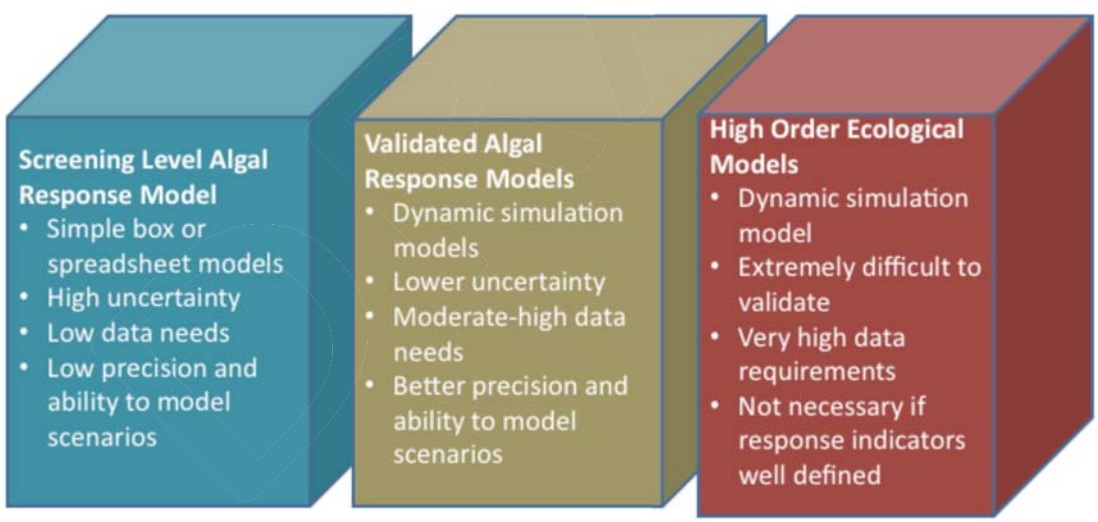
4. Load-Response Models

The goal of developing a nutrient load-response model is to use this tool to determine what load of nutrients the estuary can sustainably assimilate. The process of developing a load-response model begins with defining the problem: stating how is eutrophication expressed in the estuary and how are those symptoms linked to beneficial uses. The linkages between beneficial uses, eutrophication response indicators, and nutrient loads are explained in a detailed "conceptual model". The conceptual model must also identify the important "co-factors" -- site-specific factors such as light, temperature, tidal mixing -- that can modify the estuary's response to nutrient loads. It must also identify the important sources and pathways in which nutrients enter the estuary.



Process to develop load-response models.

The next step in developing load-response models is to determine what type of model is appropriate, based on the types of management scenarios to which the model should be responsive, state of the science; required level of precision or certainty in the answer, and the resources and data available to develop and validate the model. Models also vary in complexity -- from relatively basic screening level box models to complex dynamic simulation models that represent the estuary as thousands of small boxes (both spatially and with depth) and require a high level of computing power. While dynamic simulation models can give a more precise answer and are generally capable of modeling more advanced management scenarios, they are also very resource intensive to build and validate, requiring many years of observational data and special studies to capture all of the relevant processes. Models that simulate algal response are generally easier to develop than those attempting to simulate dissolved oxygen or high trophic level response. However, algal response models for the Bay-Delta may be atypically complex due to the multitude of processes controlling primary production.



Different types of load-response models, ranging in complexity from simple screening level models to dynamic simulation models. .

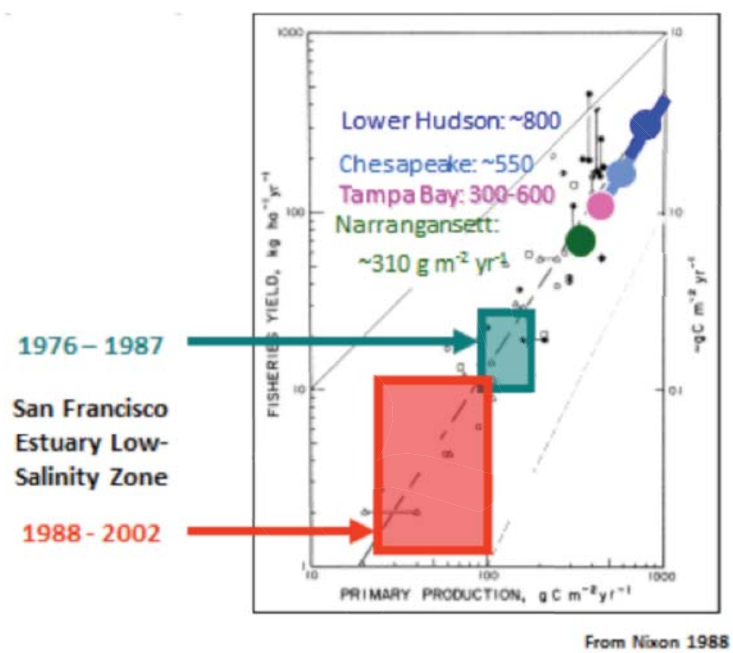
For the Bay-Delta Estuary, it will be desirable over the long-term to develop a complex, dynamic simulation model of estuary load-response, because nutrient management decisions (for example, nutrient limits for wastewater or stormwater permits) will be very expensive to implement and therefore a high level of precision is required to answer what loads of nutrients are sustainable. However, focusing first on simpler screening level box models can help to test important assumptions in the conceptual diagram, refine data gaps, identify critical model requirements, and focus limited resources to best move the process forward.

Illustrations

[NOTE NO FIGURE PERMISSIONS YET OBTAINED--THESE ARE PROPOSED]

Figure 1.

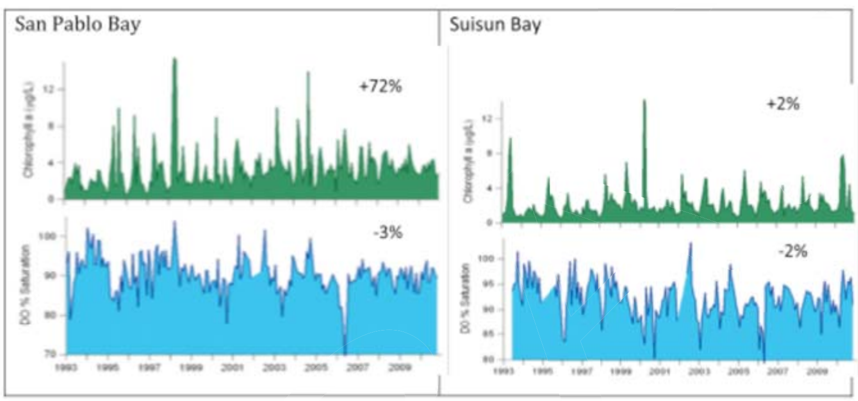
Primary production and fisheries yield in Bay-Delta Estuary are low compared to other estuaries.



Footnote: Figure from Dugdale et al. (Year?), adapted from Nixon (1988).

Figure 2.

Will the Bay turn eutrophic? Increases in phytoplankton and decreases in dissolved oxygen observed in San Francisco Bay have triggered concerns over the possible risks of eutrophication. The graphs show trends in phytoplankton biomass (as indexed by chlorophyll a concentrations) and dissolved oxygen (as % saturation) for two regions of San Francisco Bay.



Footnote: Graphs from Cloern et al. (Year?, REF)

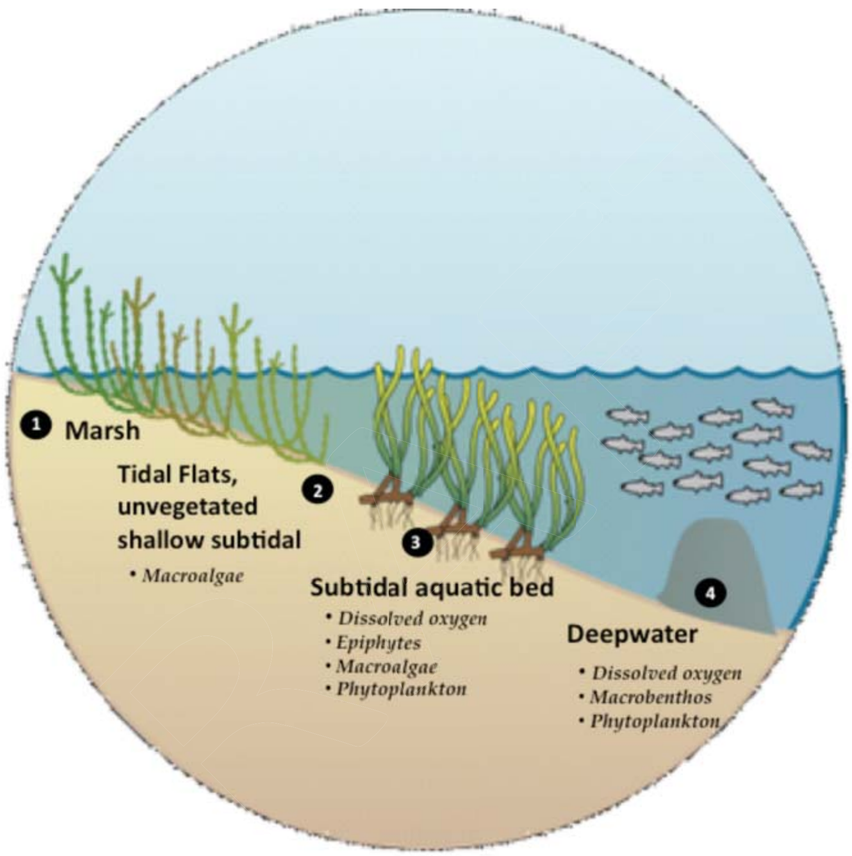
Figure 3.

Symptoms of eutrophication in the Delta. From left to right: ducks feeding in a *Microcystis* bloom, a dense bed of the invasive Brazilian waterweed *Egeria densa*, and a tidal slough choked with the invasive water hyacinth *Eichhornia crassipes*.

Footnote: Photos by….. Courtesy of DWR.

Figure 4.

Primary response indicators vary by estuarine habitat type. The figure shows primary response indicators to be used in three of the four main habitat types found in an estuary. The habitat types are found along a gradient from shoreline to open water: 1) marsh, 2) intertidal flats, 3) seagrass and brackish submerged aquatic vegetation (SAV), and 4) unvegetated subtidal. Additional supporting indicators may be used (for example, light attenuation, nutrient concentrations).



Footnote: adapted from Sutula (2011).

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d. The 303(d) List

SECTION 303(D) OF THE 1972 FEDERAL CLEAN WATER ACT requires that states develop a list of water bodies that do not meet water quality standards, prioritize the list based on the severity of the problem, and develop action plans, called Total Maximum Daily Loads (TMDLs), to improve water quality. In some cases other regulatory action plans can substitute for a TMDL. The list of impaired water bodies and the pollutants responsible is updated periodically (typically every two years).

USEPA must approve a state's 303(d) List before it is considered final. On October 11, 2011, the USEPA approved California's 2010 303(d) List, thereby replacing the 2006 California Clean Water Act 303(d) List.

The Delta is on the 2010 303(d) List. The primary pollutants/stressors identified for the Delta include:

Metals/Metalloids
Copper, Mercury, and Zinc

Pesticides
Chlordane, Chlorpyrifos, DDE, DDT, Diazinon, Dieldrin, Group A Pesticides, Organophosphorus Pesticides, and Toxaphene

Salinity
Chloride, Electrical Conductivity, Salinity, Total Dissolved Solids

Bacteria
E. coli, pathogens

Nutrients
Low Dissolved Oxygen, Organic Enrichments

Chlorinated compounds
Dioxin, Furan Compounds, PCBs

Others

Invasive Species, Temperature, Sediment Toxicity, and Unknown Toxicity[1].

The Regional Water Board and State Water Board are currently developing the draft 2012 303(d) List. The State Water Board received over 100 data submissions to support List development, each including multiple data sets for one or more pollutants. Among those submitting data were government agencies, municipalities, environmental groups, citizen groups, and National Pollutant Discharge Elimination System (NPDES) dischargers. USEPA approval of the 2012 303(d) list is expected in 2013.

More information on the 303(d) List and TMDLs is available from these websites:

303(d) List for Region 5 (which includes the Delta)

http://www.waterboards.ca.gov/centralvalley/water_issues/tmdl/impaired_waters_list/index.shtml

TMDLs

http://www.waterboards.ca.gov/centralvalley/water_issues/tmdl/index.shtml

[1] Water and sediment toxicity is observed in tests, but the cause is unknown.

e. Regulatory Status of Delta Pollutants of Concern

Pollutant	Status
Mercury	TMDL approved in 2011 (Delta Methylmercury TMDL)
Pathogens	TMDL approved in 2008 (Stockton Urban Waterbodies Pathogen TMDL)
Diazinon and Chlorpyrifos	TMDL approved in 2007
Salt and Boron	TMDL alternative initiated in 2006 Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS)
Dissolved Oxygen	TMDL approved in 2005 (San Joaquin River Deep Water Ship Channel TMDL)
Organochlorine Pesticides	TMDL in early development stage
Pyrethroid Pesticide	TMDL in early development stage

Approved: State Water Board and USEPA approval

4. STATUS AND TRENDS

a. The Latest Monitoring Results

NUTRIENTS

Nutrients have become a topic of much interest and debate in the Delta. One area of current consideration and concern is whether and how changes in nutrient loadings over the past three decades have impacted the productivity and structure of algae and plant communities. Recent studies suggest that elevated ammonium levels may be linked to low algal growth in Suisun Bay and the Delta, and continuing research assesses the role of total ammonia nitrogen in impacting the Delta's food web. Nutrients may play an increasingly important role in regulating productivity: because water has been getting clearer since 1999, the availability of light is thought to be less of a limitation on plant and algal growth.

Nutrient sources, phytoplankton biomass, and species composition

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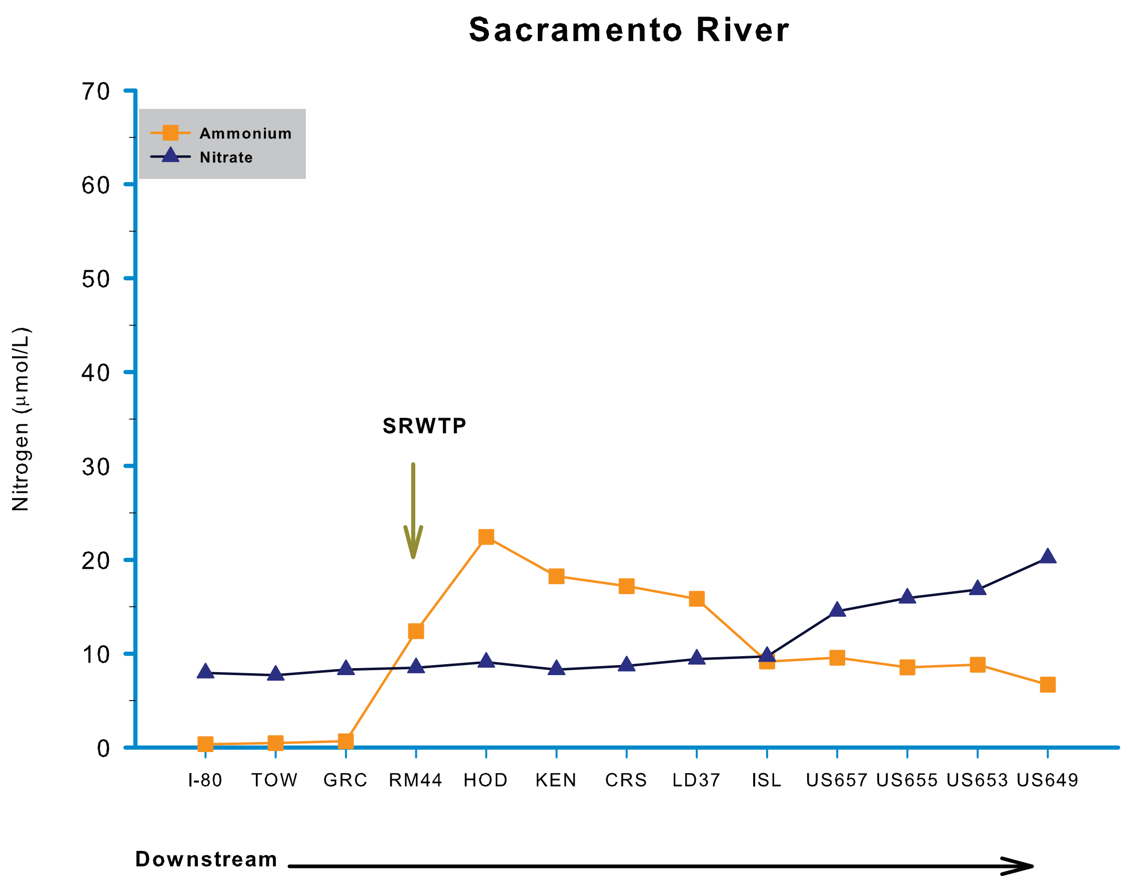
Richard Dugdale, San Francisco State University, rdugdale@sfsu.edu,
Frances Wilkerson, San Francisco State University, fwilkers@sfsu.edu, and Alex Parker, San Francisco State University, aeparker@sfsu.edu.

Fewer diatoms and other phytoplankton in ammonium-dominated Sacramento River. Delta scientists, managers, and regulators are concerned about the impacts of increased ammonium levels on the Bay-Delta ecosystem. They are currently evaluating how altered ammonium levels and nutrient balances are affecting the Delta's biological productivity and algal community composition. One way to evaluate this concern is to test the hypothesis that dominant phytoplankton functional groups are different in waters where ammonium (NH_4^+) is the dominant source of nitrogen, compared with waters where nitrate (NO_3^-) is the dominant source. To test the hypothesis, a San Francisco State University (SFSU) team monitored Delta portions of the Sacramento (ammonium-dominated) and San Joaquin (nitrate-dominated) rivers in April 2010. Both rivers receive significant portions of their nitrogen loadings from municipal wastewater discharges. The Sacramento Regional Wastewater Treatment Plant (SRWTP) discharges approximately 181 million gallons of effluent per day (mgd) to the Sacramento River and is currently the largest identified source of ammonium nitrogen to the Delta (Figure 1). The Stockton WTP releases approximately 53 mgd and is a significant source of nitrate to the San Joaquin River (**Figure 2**). Compared to the Sacramento River, the nitrate-dominated San Joaquin River had greater biomass (more algae) and a different phytoplankton community (dominated by centric diatoms). The ammonium-dominated Sacramento River community, with less biomass, was dominated mostly by flagellates and chlorophytes. Centric diatoms are considered more nutritious algae for fish larva and zooplankton, compared with flagellates or chlorophytes (**Figures 3** and **4**).

Footnote: Data and figures from Erica Kress (MSc student), Romberg Tiburon Center, SFSU. Project 1039 funded by Delta Science Program (when CALFED Science Program). Principal Investigators: Drs Richard Dugdale, Frances Wilkerson, and Alex Parker.

Nitrate (NO_3) concentrations in (blue) and ammonium (red) concentrations in micromoles per liter (µM). Algal cell numbers are based on microscope counts of phytoplankton groups (x 10^6 cells per liter) obtained using an Utermohl inverted microscope.

Figure 1.



Sacramento River
Ammonium
Nitrate
Nitrogen (µmol/L)
70
60
50
40
30
20
10
0
SRWTP
I-80
TOW
GRC
RM44
HOD
KEN
CRS
LD37
ISL
US657
US655
US653
US649
Downstream

Figure 2.

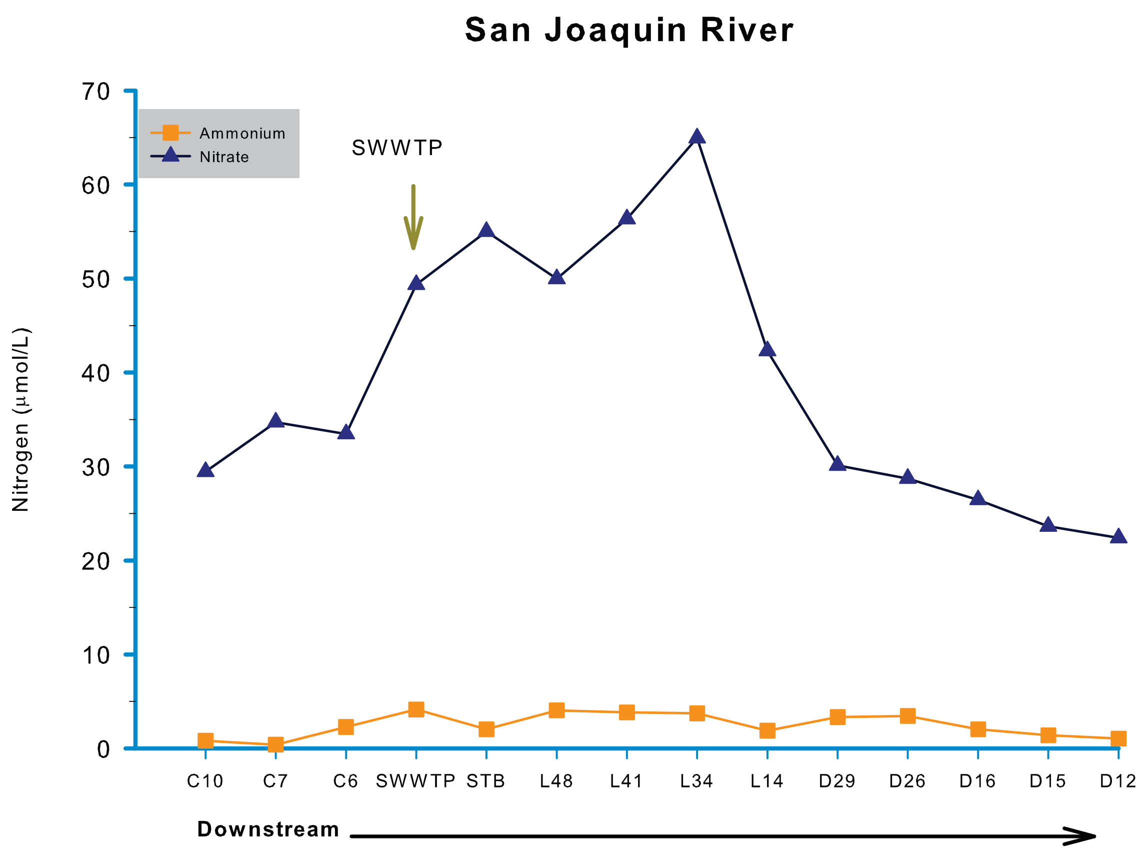

San Joaquin River
Ammonium
Nitrate
SWWTP
Nitrogen (µmol/L)
70
60
50
40
30
20
10
0
C10
C7
C6
SWWTP
STB
L48
L41
L34
L14
D29
D26
D16
D15
D12
Downstream

Figure 3.

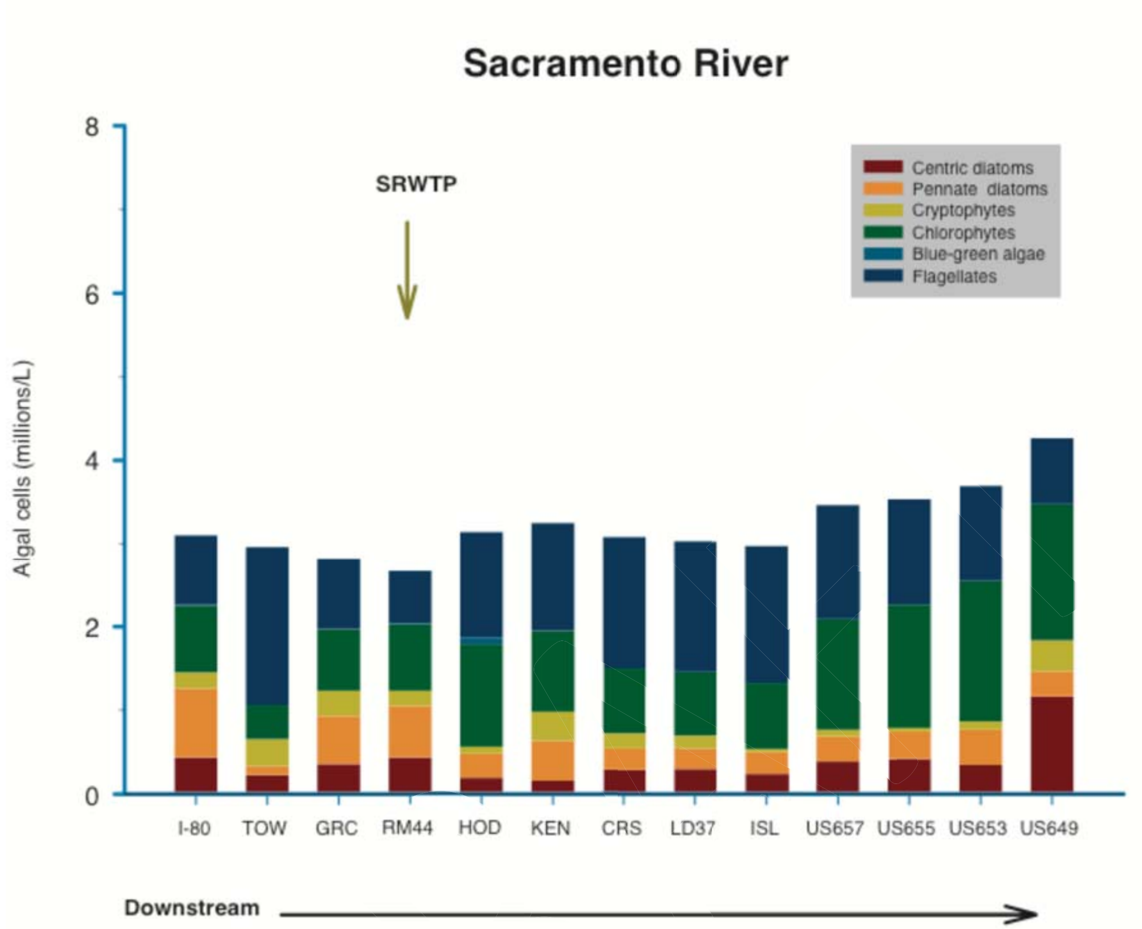
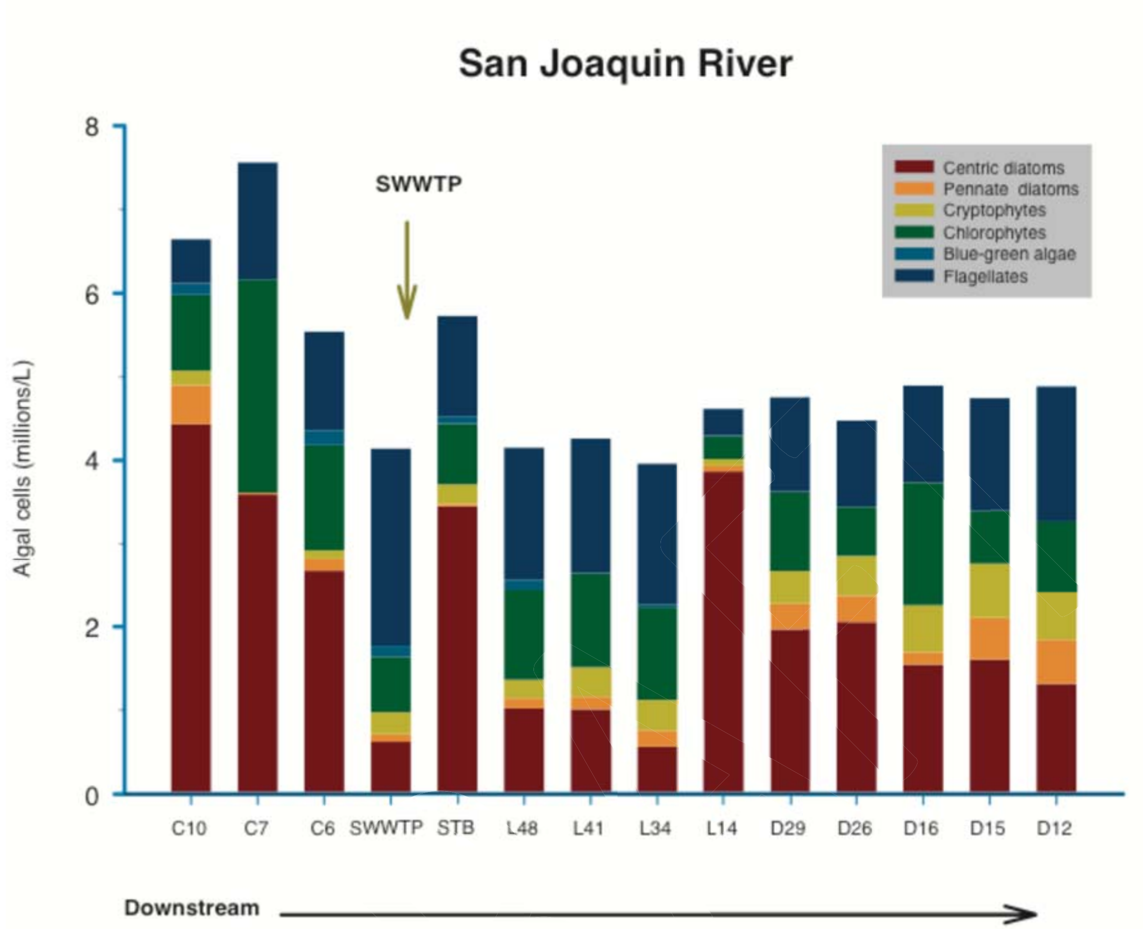

Sacramento River
SRWTP
Centric diatoms
Pennate diatoms
Cryptophytes
Chlorophytes
Blue-green algae
Flagellates
Algal cells (millions/L)
8
6
4
2
0
I-80
TOW
GRC
RM44
HOD
KEN
CRS
LD37
ISL
US657
US655
US653
US649
Downstream

Figure 4.


San Joaquin River
Algal cells (millions/L)
8
6
4
2
0
SWWTP
Centric diatoms
Pennate diatoms
Cryptophytes
Chlorophytes
Blue-green algae
Flagellates
C10
C7
C6
SWWTP
STB
L48
L41
L34
L14
D29
D26
D16
D15
D12
Downstream

Trends in Nutrient Inputs from the Sacramento and San Joaquin River

Contact:

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Thomas Jabusch, Aquatic Science Center, thomas@aquaticscience.org

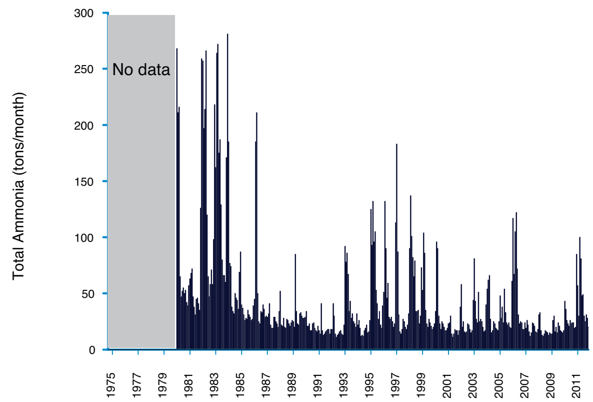
Long-term monitoring by the USGS is revealing trends in Delta nutrient loads (inputs) from upstream sources. The USGS National Water Quality Assessment (NAWQA) Program is designed to address historical, current, and future water quality conditions in representative river basins and aquifers nationwide. Investigations are conducted within “study units;” The Sacramento and San Joaquin-Tulare Basins represent two of the 51 study units in this program. The NAWQA program also monitors the mouths of large watersheds, including the Freeport and Vernalis sites, where flows from the Sacramento and San Joaquin Rivers enter the Delta.

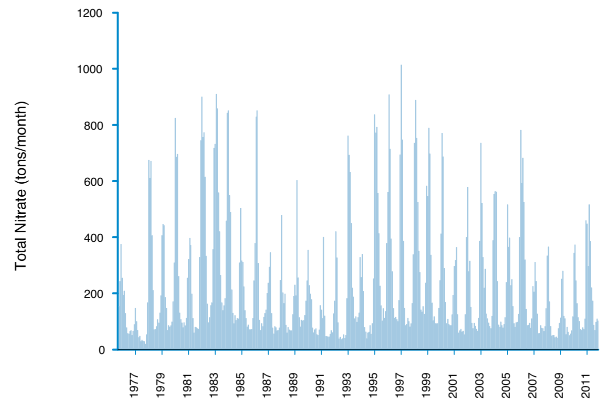
An interpretative assessment report for nutrient trends from 1975 to 2004 is now available. Shown in the graphs displayed on this page are modeling results for nutrient loads at the Freeport and Vernalis sites that include all currently available nutrient data from the National Water Information System (NWIS) database. Seasonal patterns for nutrient loads at both sites are cyclical, with maximums in winter/spring during high flow and minimums in summer/fall during low flow. Nitrate, total nitrogen (TN), and total phosphorus (TP) loads at the Freeport sites are mostly from non-point sources in the Sacramento watershed and annual loads are generally following variations in annual runoff. For ammonia, there was an overall decrease in measured loads after 1985 at Freeport, when the point of discharge of the Sacramento Regional Wastewater Treatment Plant moved to a location downstream of the monitoring site.

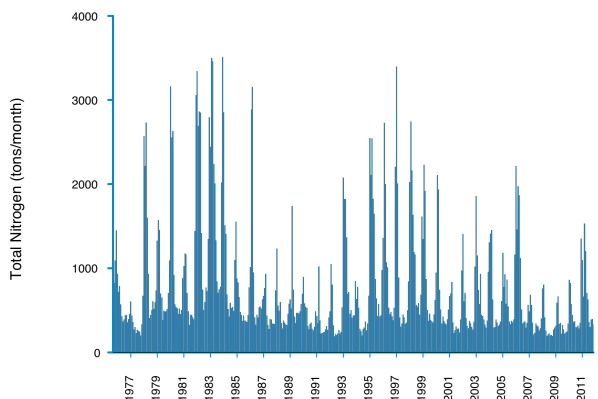
As revealed in a source analysis for the period 1985 – 2004, point sources accounted for about 4 percent of TN and 7 percent of TP loads in the Sacramento River at Freeport and for about 8 percent of TN and 17 percent of TP loads in the San Joaquin River near Vernalis. Point source contributions to TP loads at Freeport and TP and TN at Vernalis decreased over the 20 years.

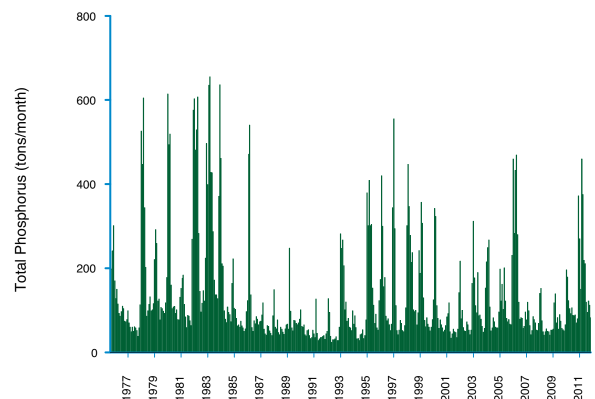
The most recent data (2005 -2011) have not yet been fully analyzed and interpreted.

Freeport:

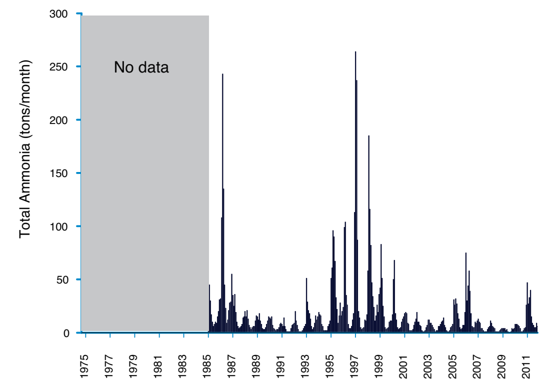

Total Ammonia (tons/month)
No data

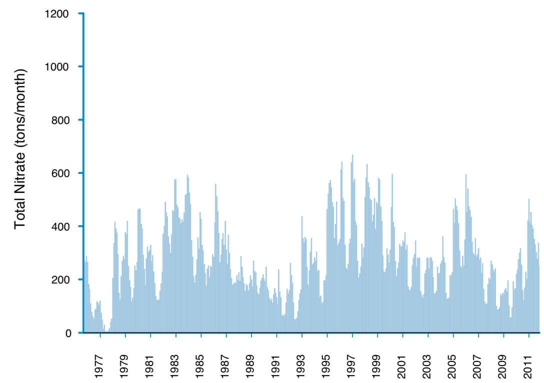

Total Nitrate (tons/month)

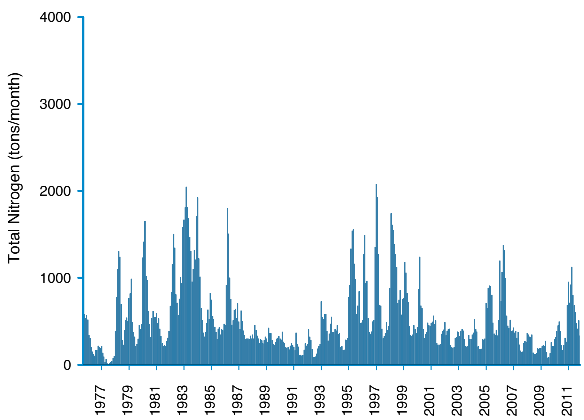

Total Nitrogen (tons/month)

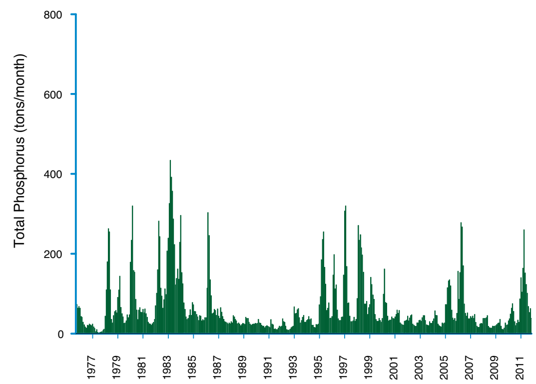

Total Phosphorus (tons/month)

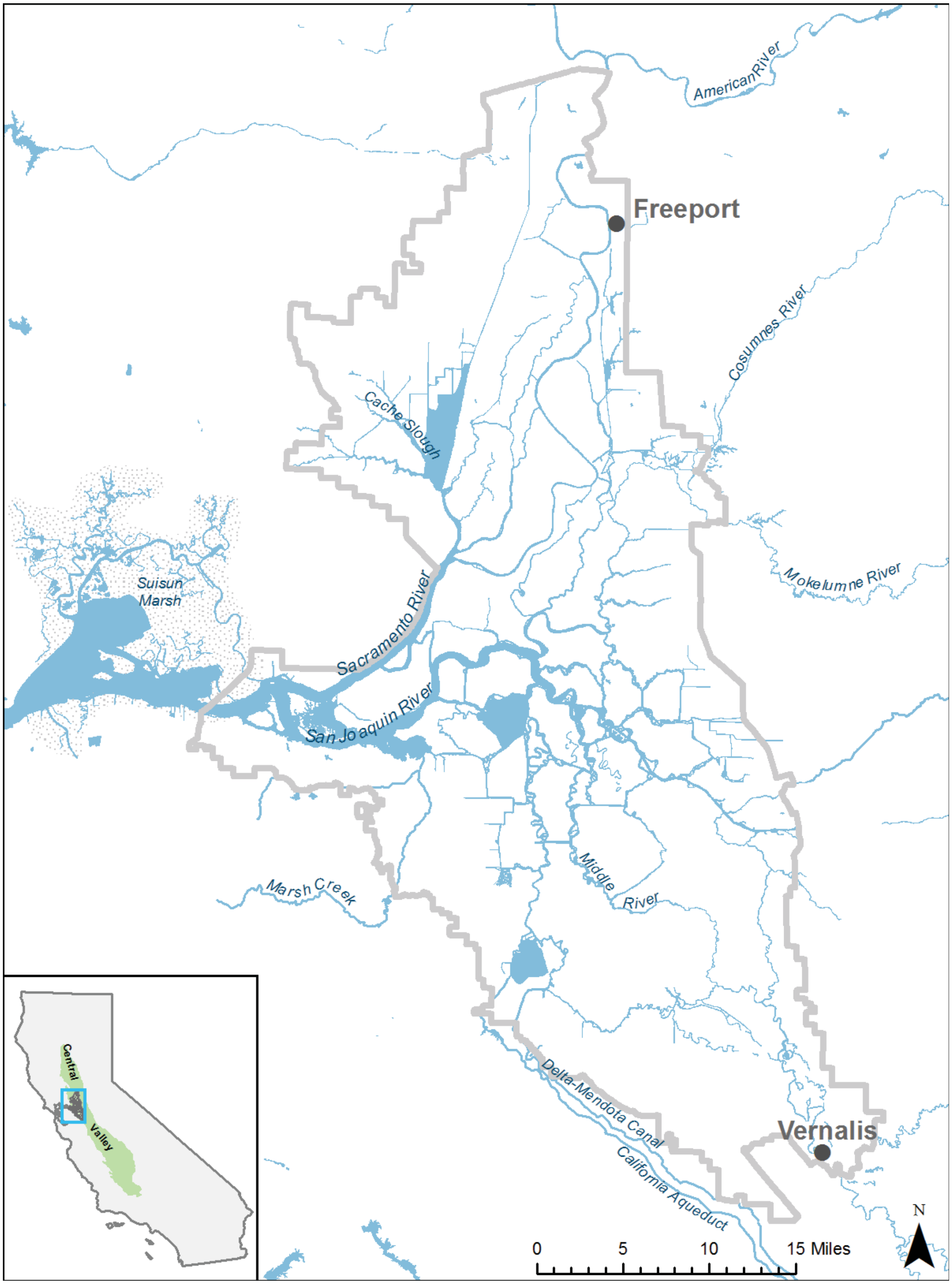
Vernalis:


Total Ammonia (tons/month)
No data
300
250
200
150
100
50
0
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011


Total Nitrate (tons/month)
1200
1000
800
600
400
200
0
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011


Total Nitrogen (tons/month)
4000
3000
2000
1000
0
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011


Total Phosphorus (tons/month)
800
600
400
200
0
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011

1 
American River
Freeport
Cosumnes River
Cache Slough
Suisun Marsh
Mokelumne River
Sacramento River
San Joaquin River
Middle River
Marsh Creek
Delta-Mendota Canal
California Aqueduct
Vernalis
Central Valley
0 5 10 15 Miles
N

2

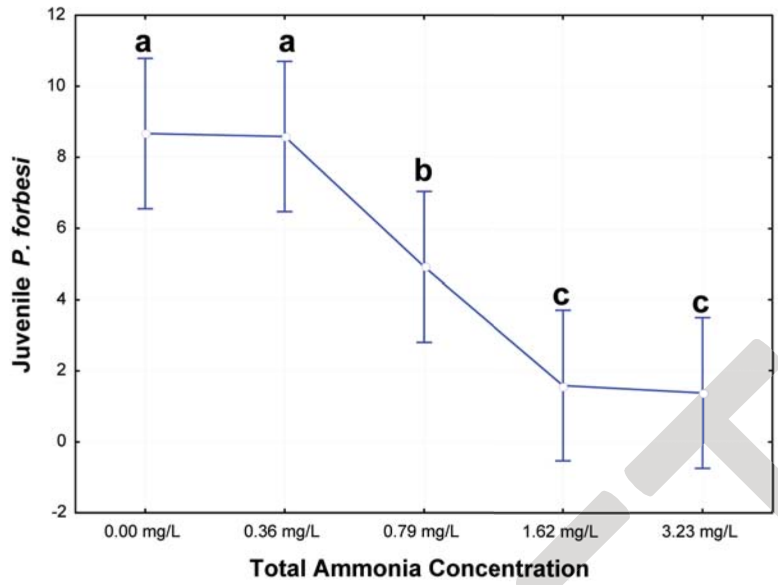
AMMONIA TOXICITY

Contact: Swee Teh, U.C. Davis, sjteh@ucdavis.edu

Current levels of ammonia in the Sacramento River may have effects on the abundance of Delta zooplankton. Increased levels of ammonia are one of the top water quality concerns in the Delta and evaluating their role in the ecosystem is a priority of regulators and managers. Elevated levels of ionized ammonia or ammonium can suppress the growth of diatom algae and, thus, may be linked to low foodweb productivity in the Delta and Suisun Bay. At high enough levels, ammonia is also known to be toxic to fish and invertebrates. Although ambient levels of ammonia are unlikely to be above toxic thresholds for fish in the Delta, investigations continue on their potential effects on some key invertebrates in the foodweb.

Swee Teh and his research group at U.C. Davis have investigated the chronic effects of ambient ammonia levels on the copepod *Pseudodiaptomus forbesi*, a zooplankton species that is an important forage organism for larval fish in the Delta. They report that ammonia levels measured in the Sacramento River below the outfall of the Sacramento Regional Wastewater Treatment Plant (SRWTP) could affect the survival of larvae and reproduction of the copepod.

Teh's team conducted a full life-cycle bioassay for total ammonia nitrogen (TAN) with the copepod in a laboratory setting. In the bioassay, TAN at 0.36 mg/L significantly affected the survival of copepod larvae and their recruitment to adult stages. Concentrations greater than 0.79 mg/L also affected reproduction in adult copepods. For comparison, 0.46 mg N/L was the average ammonia level in the Sacramento River below the SRWTP measured in a Regional Water Board study conducted in 2009 and 2010. In conclusion, the results indicate that chronic exposure of *P. forbesi* to TAN at concentrations observed in the Delta can impact adult copepod recruitment, with possible effects on the abundance of copepods.



Footnotes:

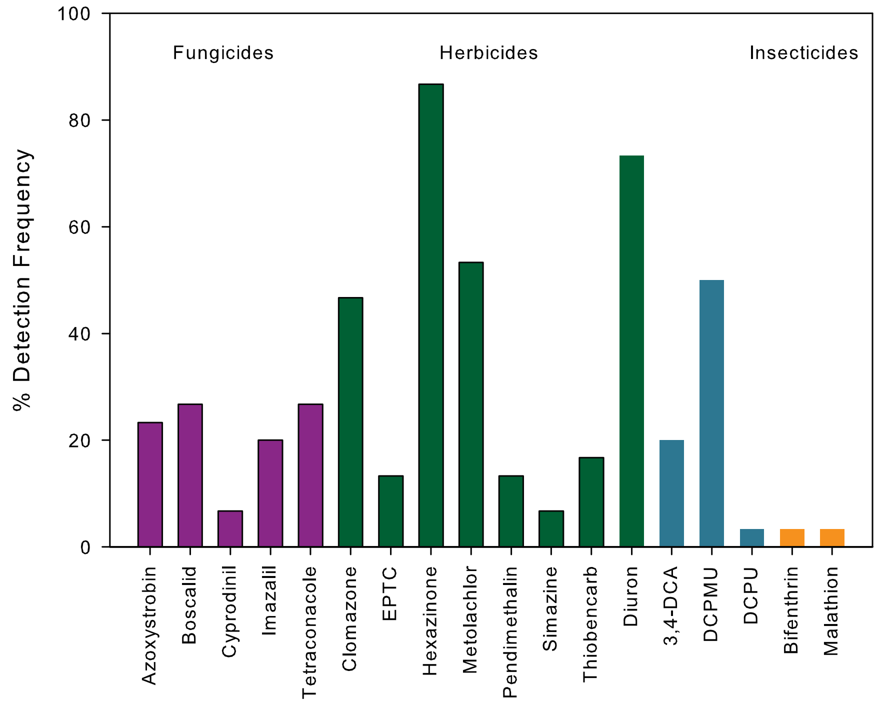
The figure shows a dose-response relationship of TAN exposures and the mean number of juvenile P. forbesi production in each treatment concentration during the 31 days of TAN exposure. Different letters indicate significant difference (P<0.05) among ammonia treatments. (Bars = 0.95 confidence intervals).

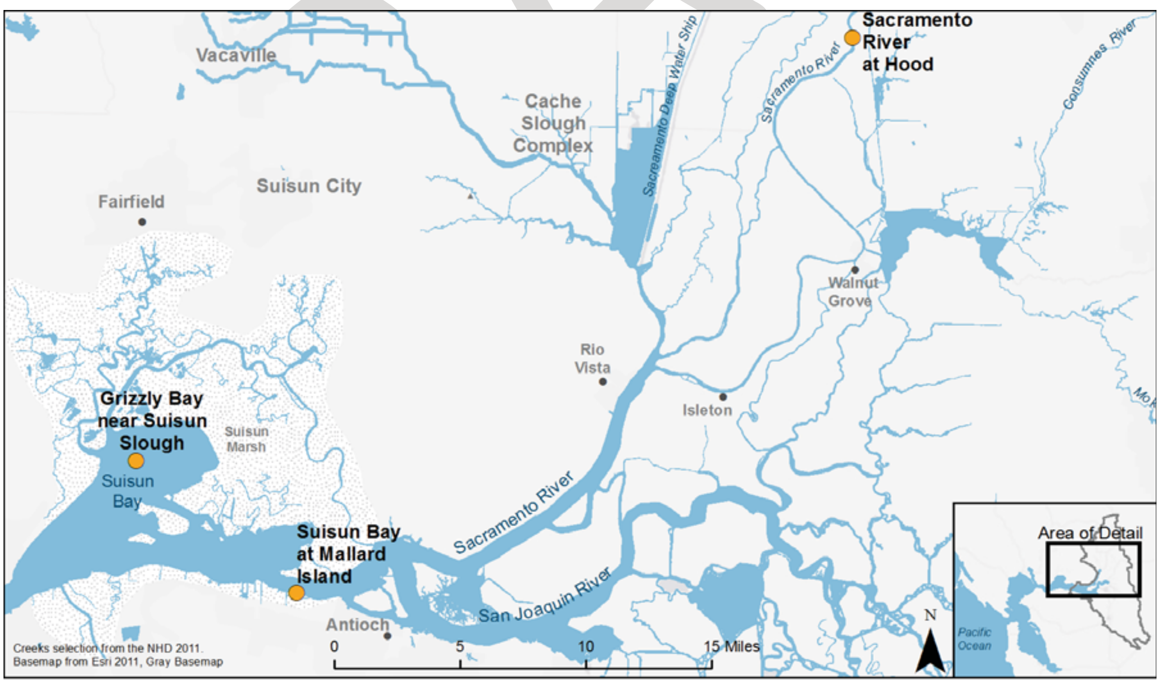
For the full report, go to http://www.swrcb.ca.gov/rwqcb5/water_issues/delta_water_quality/ambient_ammonia_concentrations/tehetal_ammonium_exposure2011.pdf.

CURRENT-USE PESTICIDES

Contact:
James Orlando, U.S. Geological Survey California Water Science Center, jorlando@usgs.gov

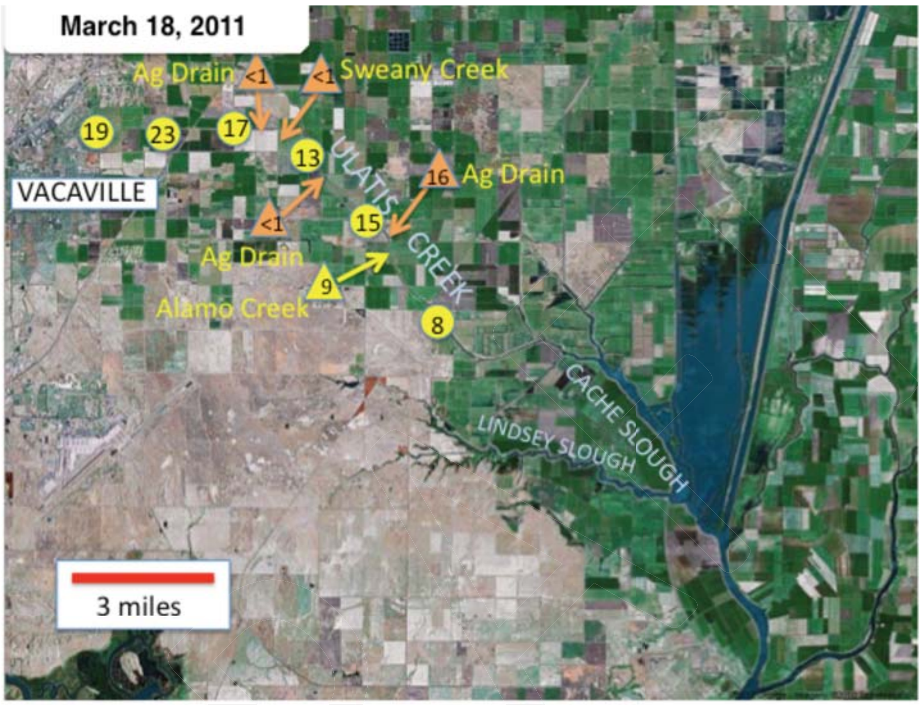
Pesticides currently in use pose a potential but unknown risk to aquatic organisms in the San Francisco Estuary. Pesticide use in the Estuary watershed is constantly changing, presenting a challenge for resource managers and policy makers trying to understand the fate and effects of these contaminants. Less than half of the pesticides currently applied in the watershed are routinely analyzed in monitoring studies and new pesticides are continually being registered for use. In a recent U.S.G.S. study of pesticides entering Suisun Bay, water samples were collected weekly from April through June of 2011 at three sites and analyzed for more than 100 compounds. Eighteen pesticides were detected, including five rarely monitored for fungicides. The herbicides hexazinone and diuron and the diuron degradation product 3,4-DCA were detected most frequently.

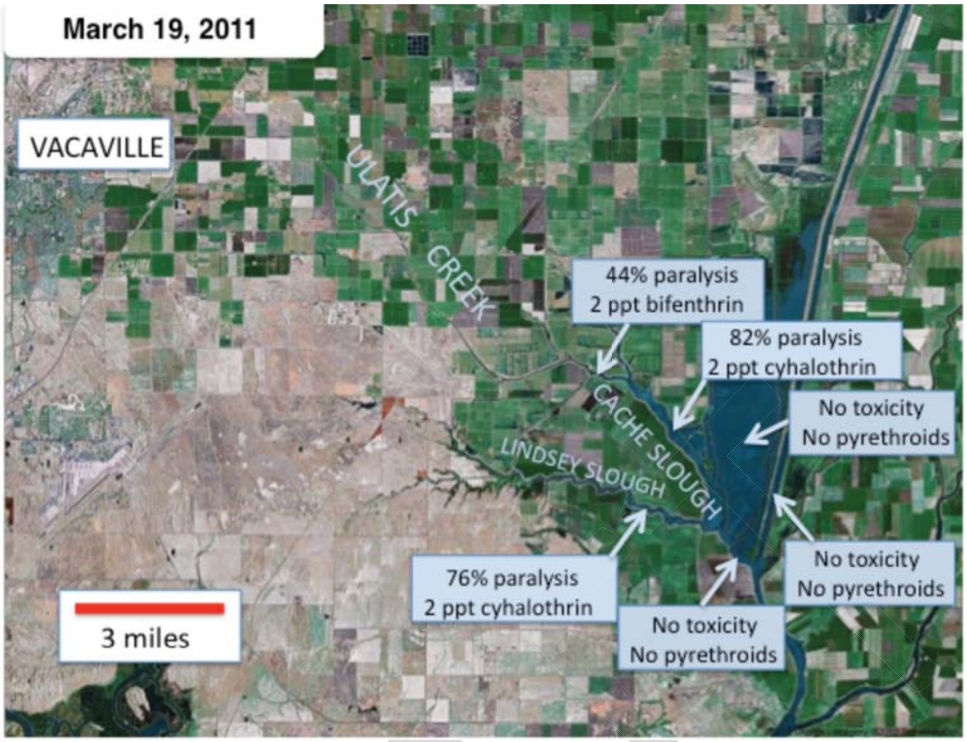

% Detection Frequency
100
80
60
40
20
0
Fungicides
Herbicides
Insecticides
Azoxystrobin
Boscalid
Cyprodinil
Imazalil
Tetraconacole
Clomazone
EPTC
Hexazinone
Metolachlor
Pendimethalin
Simazine
Thiobencarb
Diuron
3,4-DCA
DCPMU
DCPU
Bifenthrin
Malathion


Vacaville
Cache Slough Complex
Sacramento Deep Water Ship
Sacramento River
Sacramento River at Hood
Consumnes River
Fairfield
Suisun City
Walnut Grove
Rio Vista
Isleton
Grizzly Bay near Suisun Slough
Suisun Marsh
Suisun Bay
Suisun Bay at Mallard Island
Sacramento River
San Joaquin River
Antioch
0
5
10
15 Miles
N
Area of Detail
Pacific Ocean
Creeks selection from the NHD 2011.
Basemap from Esri 2011, Gray Basemap

PYRETHROID TOXICITY IN CACHE SLOUGH

Contact: Don Weston, U.C. Berkeley, dweston@berkeley.edu





Footnote: Data are from a study by Donald Weston (U.C. Berkeley) and Michael Lydy (Southern Illinois University), funded by the Surface Water Ambient Monitoring Program (SWAMP) and the IEP.

Pyrethroid insecticides in urban and agricultural runoff cause toxicity in Cache Slough Complex. Cache Slough receives pyrethroid insecticides from both urban and agricultural runoff. The yellow circles on the upper figure indicate the concentration (parts per trillion or ppt) of the pyrethroid bifenthrin in Ulatis Creek as it flows from Vacaville to Cache Slough on March 18, 2011, following rainfall of about 0.8 inches. Urban runoff from Vacaville resulted in 19 ppt bifenthrin in the creek. For comparison, acute toxicity (mortality or other adverse effect from a short-term exposure) to sensitive aquatic species occurs at about 1 ppt for most pyrethroids. Arrows indicate other inputs along Ulatis Creek that were monitored, including agricultural drains, a creek dominated by agricultural runoff (Sweany Creek) and another urban source (Alamo Creek draining southern Vacaville) that also contributed bifenthrin to Ulatis Creek.

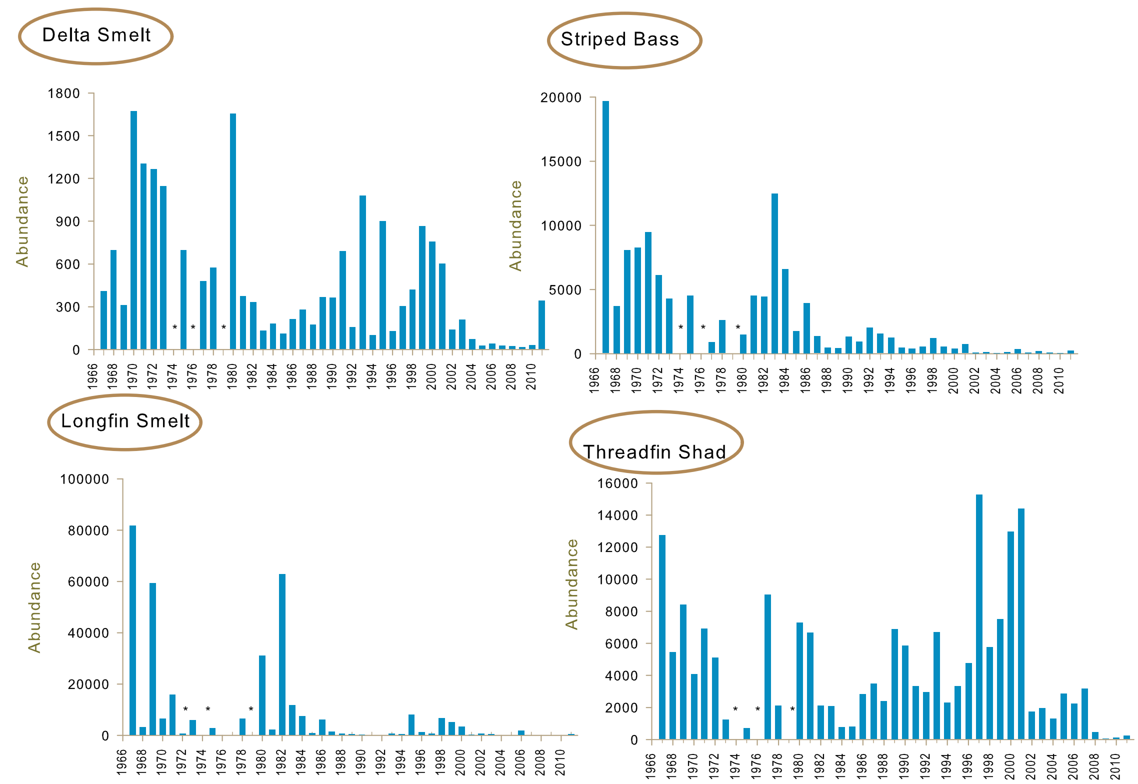
The following day (March 19, 2011), Cache Slough and adjacent water bodies were tested for toxicity using the amphipod *Hyalella azteca*. Toxicity was observed in both upstream and downstream portions of Cache Slough. A Toxicity Identification Evaluation confirmed bifenthrin originating from Ulatis Creek as the cause of the toxicity observed in upper Cache Slough. Runoff from an agricultural drain containing 1235 ppt lambda-cyhalothrin is believed to have caused the toxicity observed in downstream portions of Cache Slough and Lindsey Slough.

b. Ecosystem Trends at a Glance

Pelagic Organism Decline (POD)

Contact:

Randy Baxter, California Department of Fish and Game (CDFG), rbaxter@dfg.ca.gov

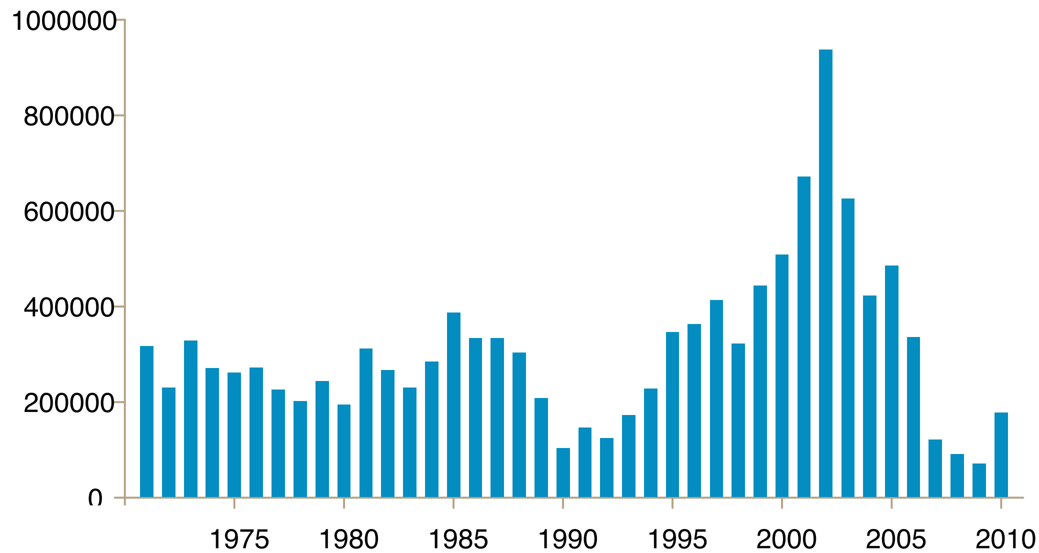


In 2011, three of four pelagic fish species remain in decline; delta smelt abundance jumps. For the last ten years, fall abundance indices for four pelagic fishes in the northern estuary have hovered at or near record low levels. Declines in these fish beginning after 2000 became known as the "pelagic organism decline (POD)". The fall indices have been collected for all but three of the last 44 years. In 2011, numbers of delta smelt caught during the fall survey increased significantly and were the highest since 2001. Numbers of caught age-0 striped bass and longfin smelt were slightly higher in years since 2006. The threadfin shad index is the third lowest in the 44-year data record. For more information about the POD and studies to investigate its causes, see http://www.water.ca.gov/iep/.

Footnote: Fish abundance data are from the Fall Midwater Trawl Survey, which is conducted by the California Department of Fish and Game as part of the IEP (http://www.dfg.ca.gov/delta/projects.asp?ProjectID=FMWT). No indices were calculated in 1974, 1976, and 1979.

Central Valley Salmon Returns

Contact:
Thomas Jabusch, Aquatic Science Center, thomas@aquaticscience.org



Trend of decreasing annual returns of Chinook salmon to the Sacramento and San Joaquin river systems reverses in 2010. The decline of salmon populations in the Sacramento and San Joaquin river systems over the past several decades has been well documented. Signs of recovery throughout the 1990s with an increasing trend in populations were followed by a decline to record low numbers in 2008 (91,437) and 2009 (71,449), resulting in the complete closure of both fishing seasons. In 2010, the escapement estimate for Chinook salmon returning to hatcheries and natural areas of the Central Valley was the highest since 2006 (178,464 fish), and a very limited season was authorized. The decline after 2005 appears to be due to poor ocean conditions leading to poor ocean survival of one or two year old fish. The rapid and likely temporary deterioration in ocean conditions is believed to be acting on top of a long-term decline in freshwater and estuarine conditions, including pollution, diversion, and loss of shallow habitats.

Footnote: Central Valley escapement data are from the GrandTab report, which is compiled by CDFG (http://www.calfish.org/tabid/104/Default.aspx). The GrandTab report is a compilation of escapement estimates of the late-fall, winter, spring, and fall-run Chinook salmon in the California Central Valley, based on counts of fish entering hatcheries and migrating past dams, carcass surveys, live fish counts, and ground and aerial redd counts. Source: Jason Azat, CDFG (jazat@dfg.ca.gov).

References

Azat, J. 2011. Central Valley Chinook harvest and escapement. IEP Newsletter, V. 24(1), p. 40-43.

Bennett, WA., and P. Moyle. 1996. Where have all the fishes gone? Interactive factors producing fish declines in the Sacramento-San Joaquin Estuary, in: Changing ecosystems: a brief ecological history of the Delta, p. 519-542. http://cdm15025.contentdm.oclc.org/cgi-bin/showfile.exe?CISOROOT=/p267501ccp2&CISOPTR=1722&filename=1723.pdf

Lindley, ST, Grimes, CB., Mohr, MS., et al. 2009. What caused the Sacramento River fall Chinook stock collapse? National Marine Fisheries Service, Long Beach, California. http://swr.nmfs.noaa.gov/media/SalmonDeclineReport.pdf

Moyle, PB., Bennett, WA., Dahm, C., et al. 2010. Changing ecosystems: a brief ecological history of the Delta. http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/deltaflow/docs/intro_delta_history_14feb2010.pdf

Freshwater Inflow into the Delta

Contact:

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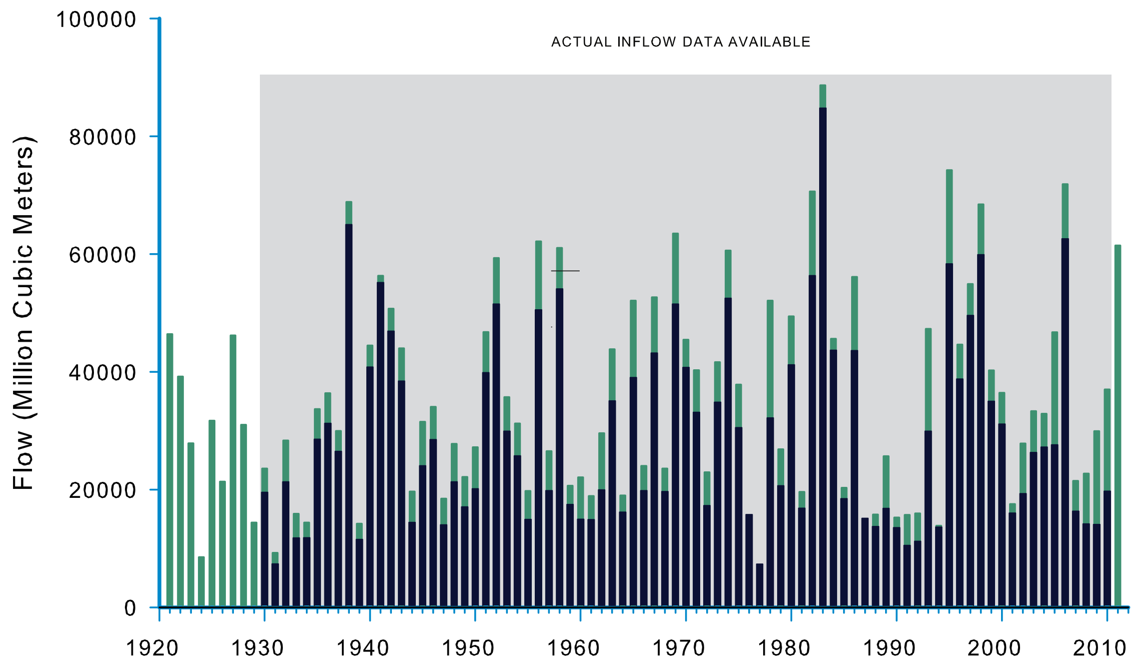

High annual freshwater inflow into the Delta in 2011. This graph compares actual annual inflows to the Delta (blue) with unimpaired flow (green), which is runoff that would have occurred, had water flow remained unaltered in rivers and streams, instead of stored in reservoirs, imported, exported, or diverted. It is indicative of the total water supply available. Streamflow totals, as indicated by unimpaired runoff, fluctuate widely from year to year, making it challenging for water resource managers to balance supplies, water rights, environmental-flow requirements, and conveyance capacities. The fluctuations also make it more challenging to measure trends in pollutant inputs and water quality, which are heavily influenced by flow. Flow records for the Central Valley date back to October 1921. Following the 2007-09 drought and a lower-than-average year in 2010, 2011 was the ninth-wettest year (61,449 million cubic meters) on record.

Footnote: Data from the California Department of Water Resources (DWR). Estimated unimpaired flows from 1921 to 2003 are from the California Central Valley unimpaired flows dataset. For 2004-2010, annual and monthly unimpaired flows were calculated by a regression developed from the Central Valley unimpaired flow data (using the 1930-1994 *period) and the corresponding unimpaired runoff estimates from the "Full Natural Flows" (FNF) dataset for the ten largest rivers in the watershed (Christina Swanson, personal communication). Actual inflows are from the*

Delta inflow data are from Dayflow (http://www.water.ca.gov/dayflow/). Data inflow data for 2011 were not available at the time of preparing this report.

Source: DWR

References:

Dettinger, MD., Ralph, FM., Tapash, D., et al. 2011. Atmospheric rivers, floods and the water resources of California. Water (3): 445-478.

DWR. 2007. California Central Valley unimpaired flow data. Fourth edition. http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/water_quality_control_planning/docs/sjrf_spprtinfo/dwr_2007a.pdf

Outflows and Exports from the Delta

Contact:
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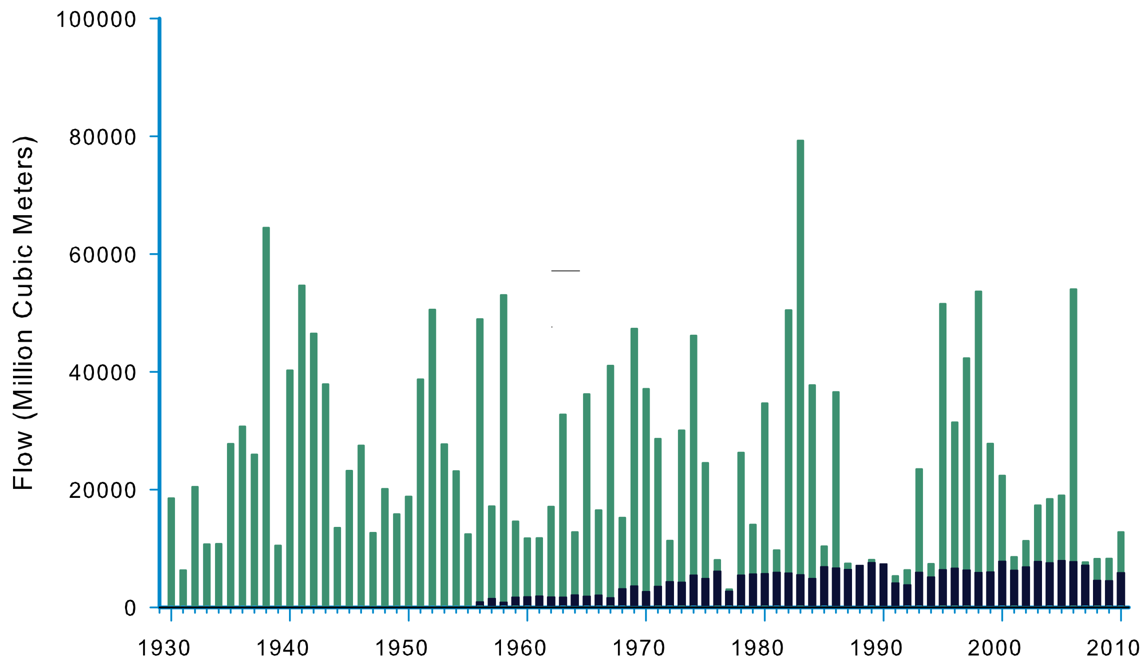


Annual outflows and exports from the Delta. This graph shows combined annual water exports from the Delta via the Central Valley Project and State Water Project (blue) and Delta outflows (green), which is an estimate of "net" flow at the confluence of the Sacramento and San Joaquin Rivers, nominally at Chipps Island. It is indicative of the physical, chemical, and biological state of the northern reach of the San Francisco Estuary. Generally, outflows and exports are higher in wet years compared to average and dry years. Since the beginning of water export operations in the Delta in the 1950s, the exports of water taken from the Delta and taken elsewhere have gradually gone up to reach approximately 15-17% of total flows for the past forty years (Blue Ribbon Task Force 2007). Annual water exports in 2008-10 were the lowest since 1994, as a result of the 2007-09 drought conditions combined with court-ordered pumping restrictions to protect the endangered delta smelt.

Footnote: Delta outflow and export data are from Dayflow (http://www.water.ca.gov/dayflow/).

The Dayflow estimate of Delta outflow is referred to as the "net Delta outflow index" (NDOI) because it does not account for tidal flows, the fortnight lunar fill-drain cycle of the estuary, or barometric pressure changes. It is a quantity that never actually occurs in real time. Rather it is an estimate of the net difference between ebbing and flooding tidal flows at Chipps Island, aliased to a daily average. Depending on conditions, the actual net Delta outflow for a given day can be much higher or lower than the Dayflow estimate.

Source: DWR

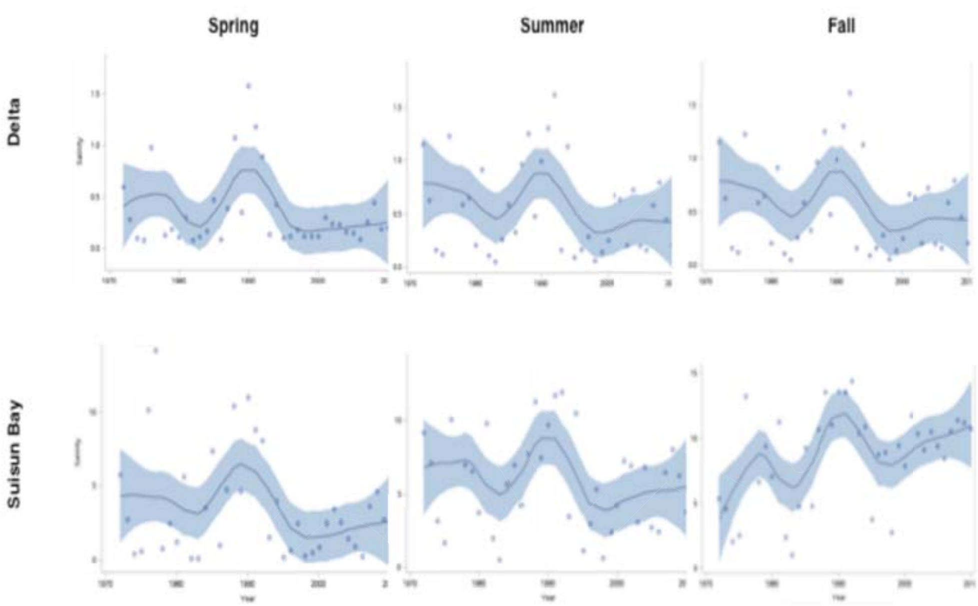
References:

Blue Ribbon Task Force. 2007. Delta Vision: Our Vision for the California Delta http://deltavision.ca.gov/BlueRibbonTaskForce/FinalVision/Delta_Vision_Final.pdf

Salinity

Contact:

Thomas Jabusch, Aquatic Science Center, thomas@aquaticscience.org



Annual and Seasonal Trends in Salinity. Brackish, or low salinity, habitat is one of the most important features of the Estuary and linked to the health of estuarine species and the ecosystem. Salinity in the Delta and Suisun Bay mirrors freshwater inflows from upstream and varies greatly among years and seasons. Generally, salinity is lower in spring and then increases in summer and fall. According to recent analyses by Monika Winder and Alan Jassby from the John Muir Institute of the Environment at U.C. Davis, salinity did increase significantly on an annual basis in both regions during 1995 – 2008. This upward trend follows a marked rise and fall in salinity centered on the dry years from 1987 to 1994. The results of the analysis also indicate a pronounced trend in Suisun Bay of increasing salinity in the fall.

Footnotes: Practical salinity values were calculated from surface electrical conductivity values using the Practical Salinity Scale. Data points are seasonal averages (spring: March –May, summer: June – August, fall: September – November). The trend line displays a Loess fit and the shaded area represents the 90% confidence limits. Data *included in the analysis are ancillary data from IEP's zooplankton monitoring collected at IEP's discrete sampling sites (Winder & Jassby 2011).*

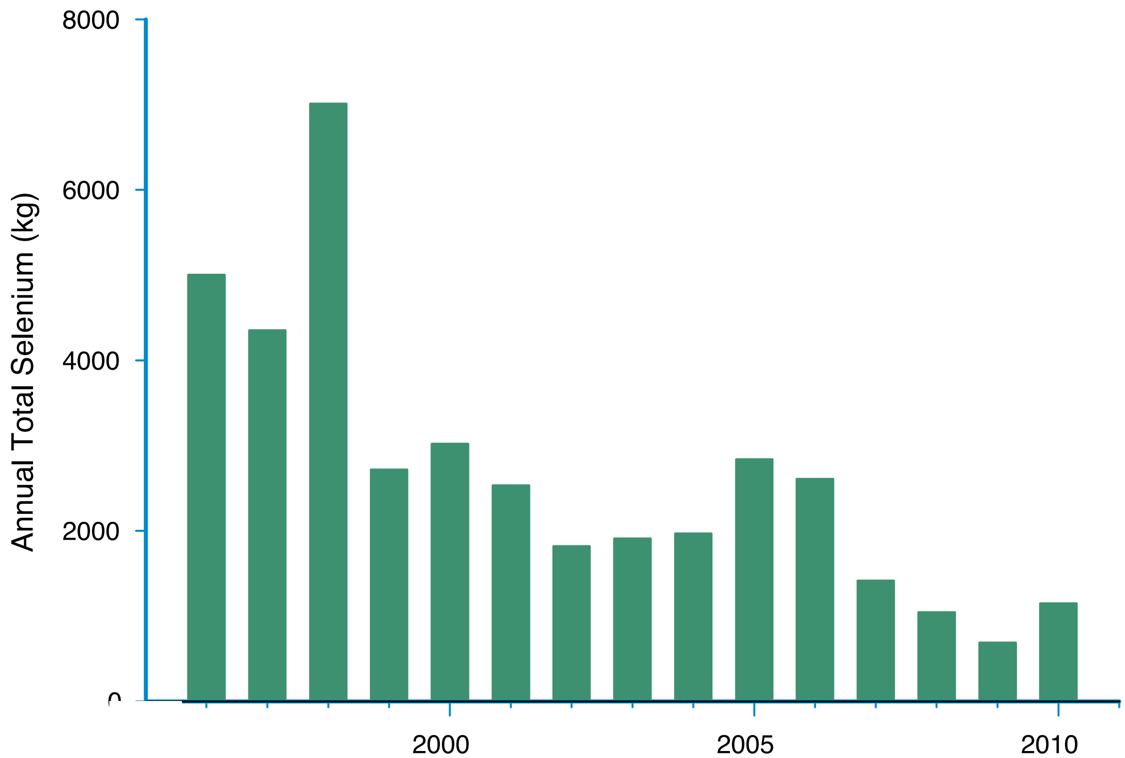
References:

Kimmerer, WJ. 2004. Open water processes of the San Francisco Estuary: from physical forcing to biological responses. San Francisco Estuary and Watershed Science 2(1). URL http://repositories.cdlib.org/jmie/sfews/vol2/iss1/art1

Winder, M., Jassby, AD. 2011. Shifts in Zooplankton Community Structure: Implications for Food Web Processes in the Upper San Francisco Estuary. Estuaries and Coasts 34: 675-690.

Selenium from the San Joaquin River

Contact:
Thomas Jabusch, Aquatic Science Center, thomas@aquaticscience.org

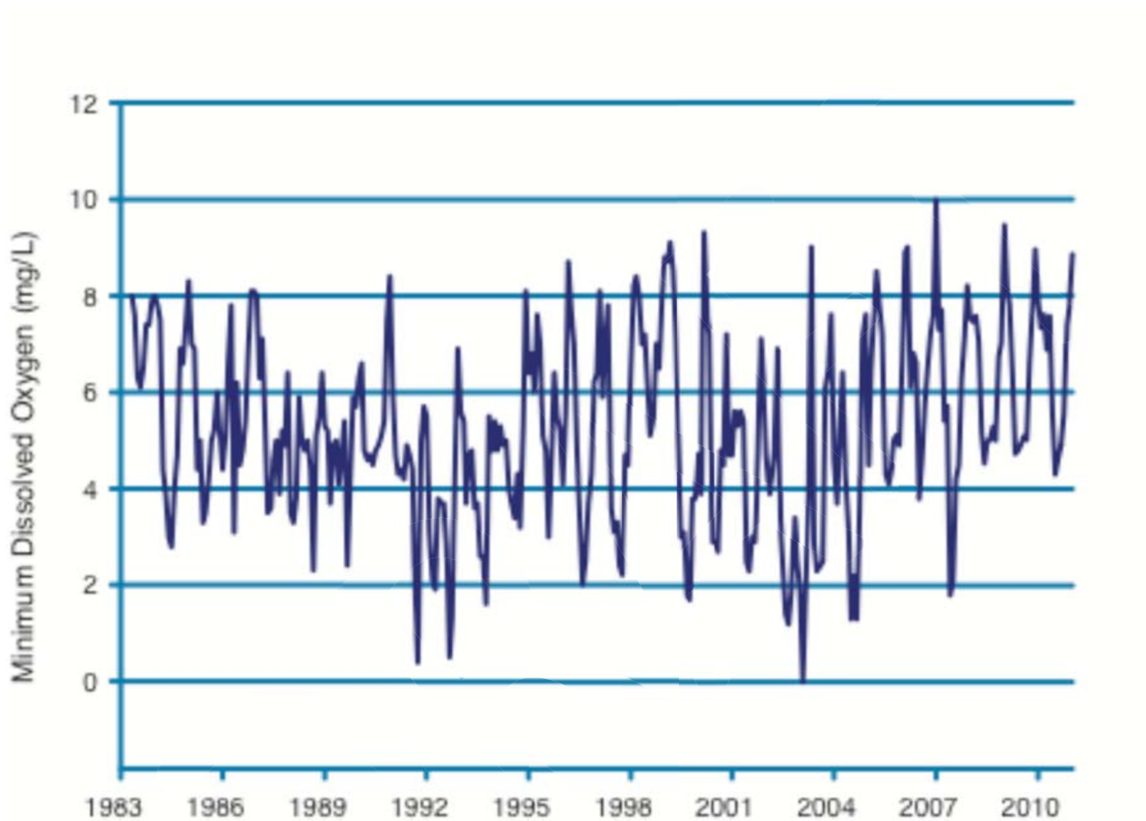


Annual Loads of Selenium from the San Joaquin River in Long-term Decline. The San Joaquin River carries significant loads of selenium and other pollutants from the intensely farmed and increasingly urbanized San Joaquin Valley into the Delta. The main controllable source of selenium is agricultural drainage from the western side of the San Joaquin Basin, where soils have naturally high selenium contents. SWAMP studies allow estimation of loads from 1996 to the present. Selenium loads have declined since 1996 in response to a control program in the Grasslands area. The annual loads for 2009 (689 kg), 2008 (1045 kg), and 2010 (1148 kg) are the lowest estimated for the 15-year period. The long-term declining trend is indicative of the rigorous management of discharges to meet annual load values and water quality objectives, with annual runoff and other factors driving some of the year-to-year fluctuations.

Footnotes: Total loads for each water year (Oct 1 – Sep 30). Loads are estimated for the Vernalis monitoring site. Daily loads were summed up to estimate annual loads. Daily load values were generated by linear interpolation from weekly total selenium concentration data collected by the SWAMP and USGS daily flow data.

Dissolved Oxygen in the Lower San Joaquin River

Contact:
Christine Joab, Central Valley Regional Water Quality Control Board, cjoab@ waterboards.ca.gov



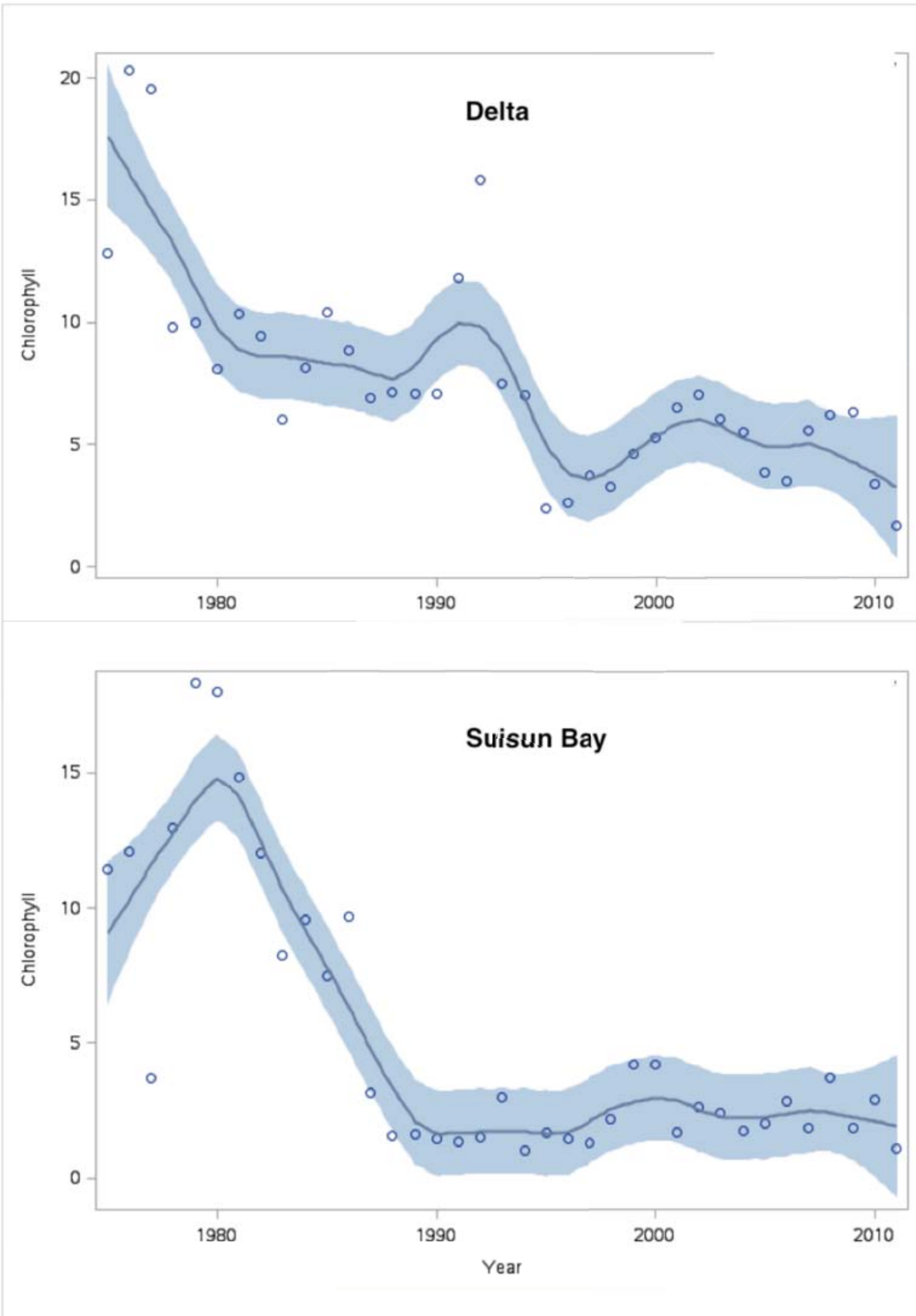
Minimum Monthly Dissolved Oxygen (DO) Values in the Lower San Joaquin River Improved but Still Falling Below Limits. Low dissolved oxygen in Delta waters pose significant migration barriers to salmon and other migrating fishes. Dissolved oxygen barriers occur in the Stockton Deep Water Ship Channel (DWSC) and on Old and Middle Rivers and have resulted in the establishment of a Total Maximum Daily Load (TMDL) to control low DO in the San Joaquin River. The deepened channel, reduced flows, decomposing algae from upstream, and oxygen-demanding substances from the City of Stockton wastewater treatment plant all contribute to the low DO issue. Dissolved oxygen in the lower San Joaquin River has increased since the early 2000s, primarily due to the implementation of algae removal ponds and nitrification treatment by the City of Stockton wastewater treatment plant. However, monthly minimum values continue to fall frequently below the statutory limits of 5 mg/L (December 1 to September 30) and 6 mg/L (October 1 to November 30).

Footnotes: Minimum monthly values of dissolved oxygen measured at the Rough and Ready Island monitoring station. Data are from the Continuous Multiparameter Monitoring by the IEP Environmental Monitoring Program.

Phytoplankton Biomass

Contact:

Thomas Jabusch, Aquatic Science Center, thomas@aquaticscience.org



Annual Trends in Phytoplankton Biomass Remain in Decline. Since the mid-1970s, chlorophyll concentrations (an indicator of phytoplankton biomass) in the Delta have declined 4-fold. There are many reasons for this decline, including reduced phosphorus loadings, increased nitrogen loadings, grazing by invasive clams, water diversions, and changed flow patterns. The downward trend in the abundance and productivity of algae in the Delta over the last few decades is combined with "demographic" changes in the phytoplankton community from large diatoms to flagellates, blue-green algae, and smaller species of diatoms. The large decline in phytoplankton biomass (as measured by chlorophyll a) in Suisun Bay occurred mostly after the introduction of the overbite clam *Corbula amurensis* in 1986, but several other drivers are thought to play a role in the observed changes to the algal community. Among them are a reduction in phosphorus loadings, increased ammonia loadings, and water diversions. Chlorophyll values below 10 μg/L are considered an indication of a food shortage for zooplankton.

Footnotes: Deltawide averages. The trend line displays a Loess fit and the shaded area represents the 90% confidence limits. Data from the IEP Environmental Monitoring Program (EMP).

Data source: Tiffany Brown, DWR

References:

Baxter, R., Breuer, R., Brown, L., Conrad, L., Feyrer, F., Fong, S., Gehrts, K., Grimaldo, L., Herbold, B., Hrodey, P., Mueller-Solger, A., Sommer, T., Souza, K. 2010. Interagency Ecological Program 2010 Pelagic Organism Decline Work Plan and synthesis of results. University of California, Davis, California. URL http://www.water.ca.gov/iep/docs/FinalPOD2010Workplan12610.pdf

Brown, T. 2009. Phytoplankton community composition: the rise of the flagellates. IEP Newsletter 22(3): 20–28.

Mueller-Solger, A.B., Jassby, A.D., Muller-Navarra, D.C. 2002. Nutritional quality of food resources for zooplankton (Daphnia) in a tidal freshwater system (Sacramento-San Joaquin River Delta). Limnology and Oceanography 47(5): 1468-1476.

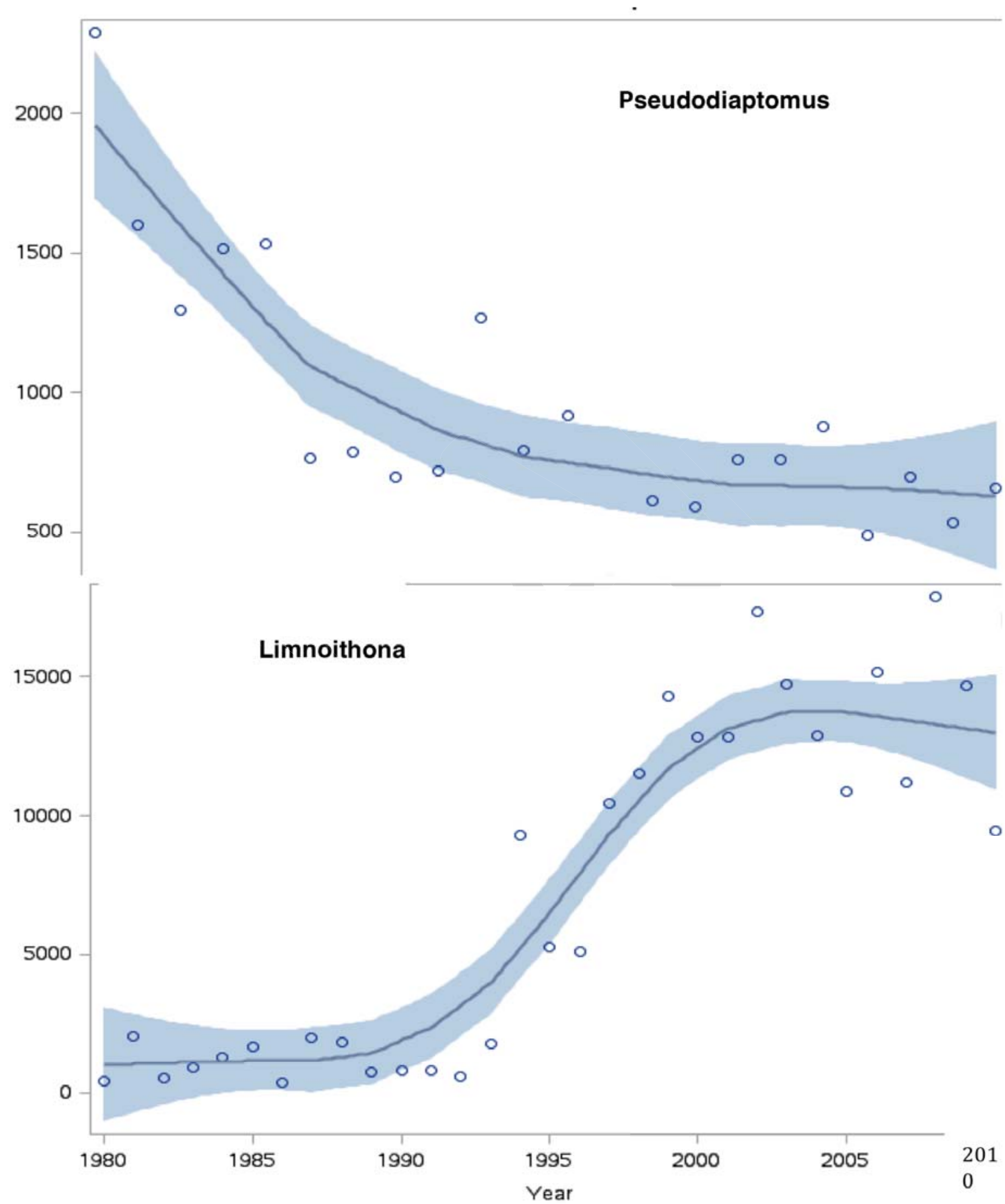
Van Nieuwenhuyse, E.E. 2007. Response of summer chlorophyll concentration to reduced total phosphorus concentration in the Rhine River (Netherlands) and the Sacramento-San Joaquin Delta (California, USA). Canadian Journal of Fisheries and Aquatic Sciences 64: 1529–1542.

Winder, M., Jassby, AD. 2011. Shifts in Zooplankton Community Structure: Implications for Food Web Processes in the Upper San Francisco Estuary. Estuaries and Coasts 34: 675-690.

Zooplankton in the Delta

Contact:

April Hennessy, CDFG, ahennessy@dfg.ca.gov



Annual Trends in Zooplankton Abundance Vary. *Limnoithona tetraspina* and *Pseudodiaptomus forbesi* are the two dominant zooplankton species of the Low Salinity Zone. Both are non-native species that belong to a group of small crustaceans called copepods ("oar-feet"). *P. forbesi* was first discovered in the upper Estuary in 1988 and has declined slightly since then. It remains relatively abundant compared to other copepods and is thought to be an important forage species for larval fish in the Delta. *L. tetraspina* was first recorded in 1993 and has since mostly supplanted the historically common and slightly larger *L. sinensis*. Despite high densities of *L. tetraspina* in the estuary, it may not be a readily available food source for visual predators, like Delta smelt, due to its small size and relatively motionless behavior in the water column. As an ambush predator that feeds on motile prey, it may have benefitted from phytoplankton composition changes from non-motile diatoms to motile flagellates.

Footnotes: Data are yearly March – November abundance averages per cubic meter of water (reported as catch-per-unit effort, CPUE). Limnoithona abundance is the abundance of L. tetraspina and L. sinensis combined for the IEP core monitoring stations. L. tetraspina was not identified separately from L. sinensis until 2007. Data from the IEP Environmental Monitoring Program (EMP). The trend line displays a Loess fit and the shaded area represents the 90% confidence limits.

References:

Bouley P. and WJ. Kimmerer. 2006. Ecology of a highly abundant, introduced cyclopoid copepod in a temperate estuary. Marine Ecology Progress Series (324): 219-228.

Brown, T. 2009. Phytoplankton community composition: the rise of the flagellates. IEP Newsletter, V. 22(3), p. 20–28.

Winder, M., Jassby, AD. 2011. Shifts in Zooplankton Community Structure: Implications for Food Web Processes in the Upper San Francisco Estuary. Estuaries and Coasts 34: 675-690.

Delta Population

Contact:

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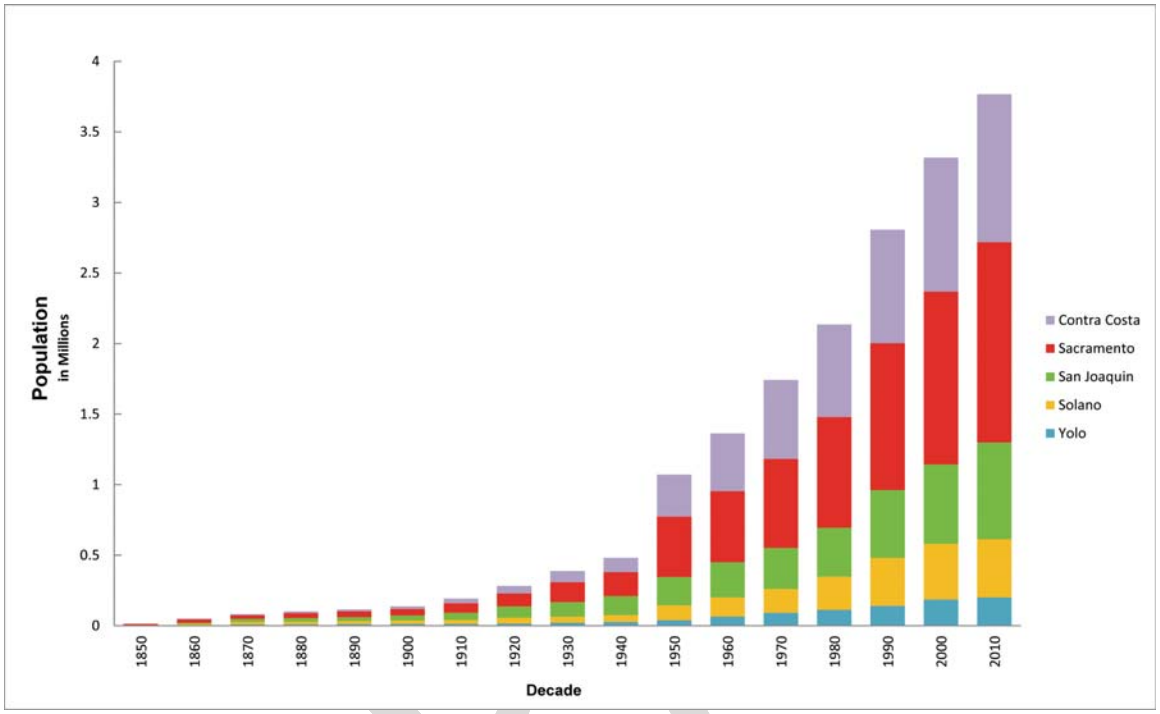

Delta Population Steadily Increasing. The large and growing human population in the Delta's watershed places increasing pressure on Delta water quality through expanding urbanization, water demands, and other mechanisms. The population of the Delta counties reached 3.8 million in 2010, compared to 3.3 million in 2000, and is predicted to grow to 4.6 million by 2020.

Footnotes: Data from the U.S. Census Bureau. Population projection for 2020 by the California Department of Finance (http://www.dof.ca.gov/html/demograp/reportspapers/projections/p1/documents/p1_press_release_7-07.pdf).

Land Cover in the Delta

Contact:

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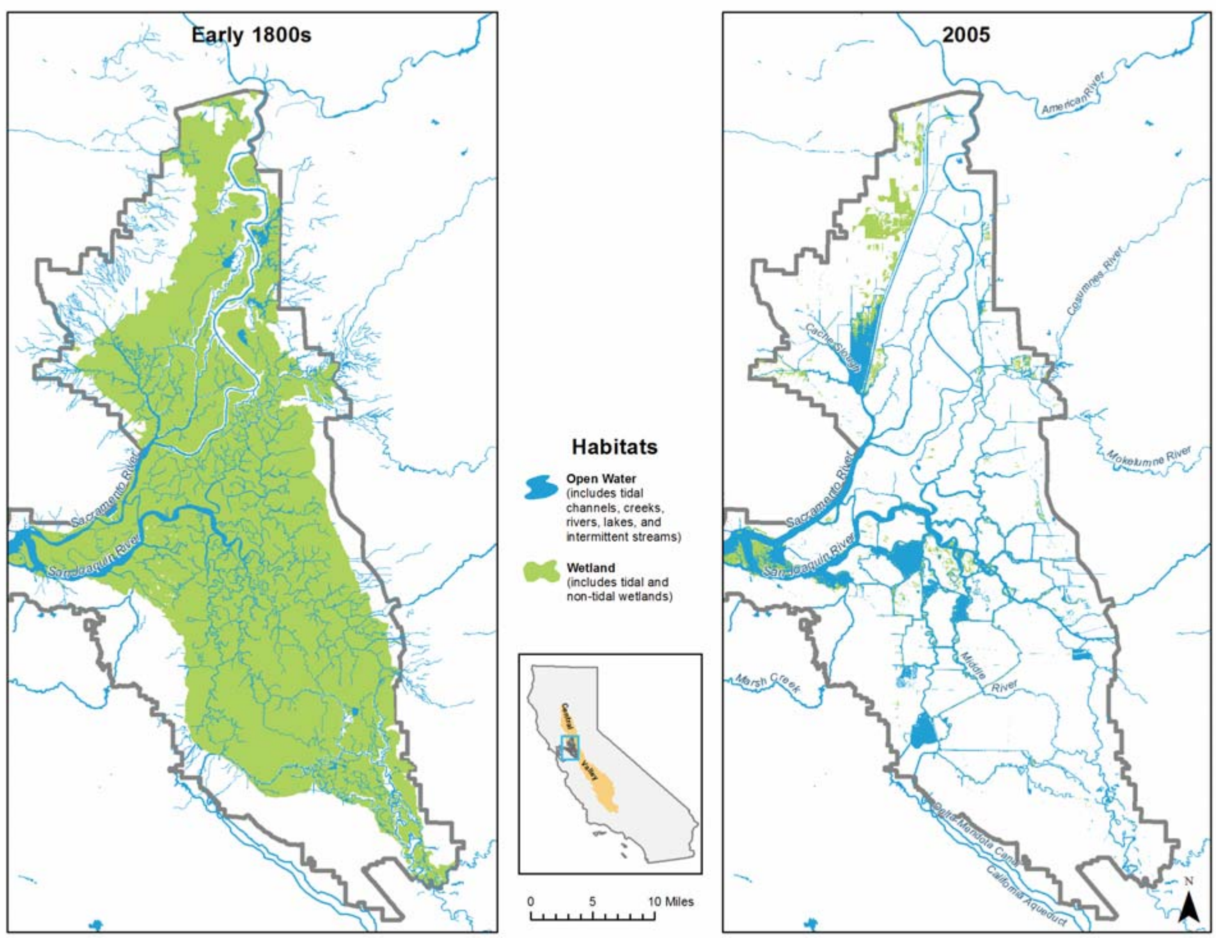
Alison Whipple, Aquatic Science Center, alison@sfei.org



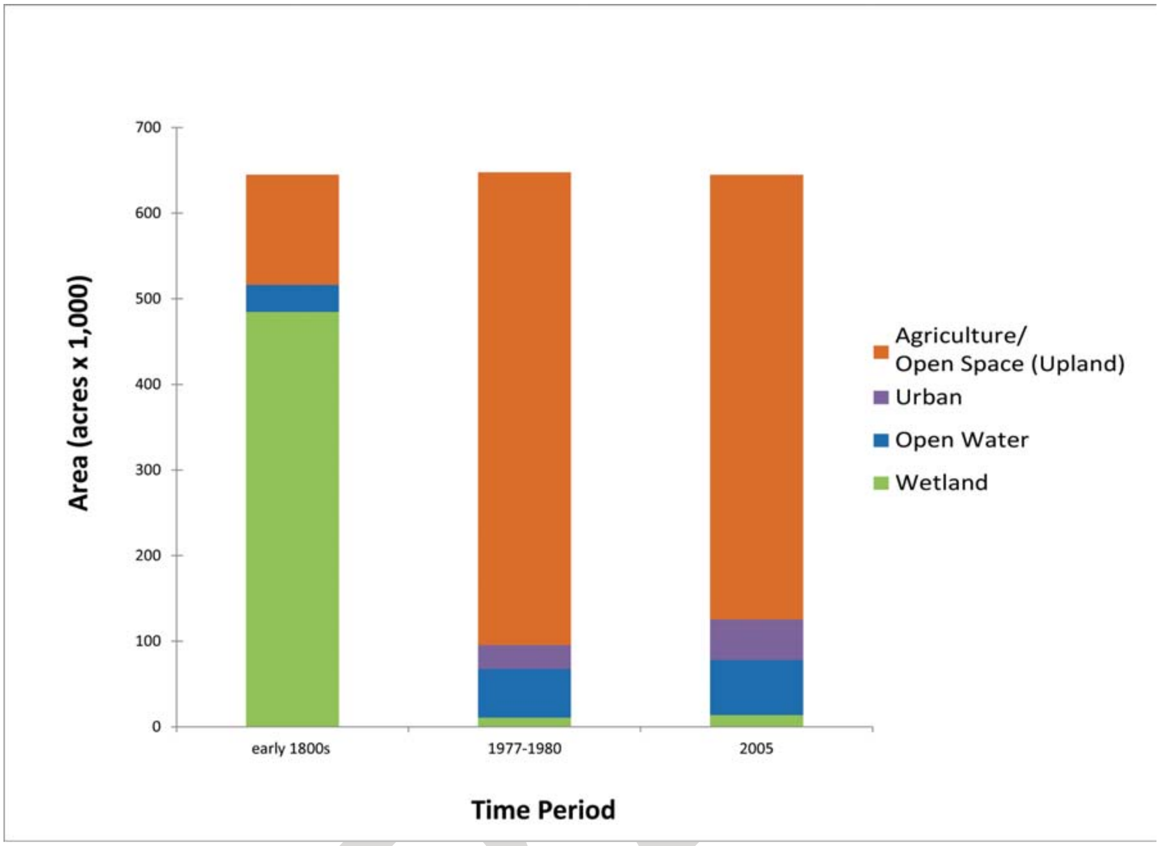
Comparison of early 1800s and early 2000s open water and wetlands in the Delta. Most apparent is the significant loss in wetland extent. The comparison also reveals reduction in historical tidal channel complexity as a result of the damming of smaller waterways, widening of channels, and cutting of short connecting channels across the necks of meanders and between waterways. This loss of the wetland landscape has profoundly affected the Delta's resilience such that other stressors, such as contaminants, have relatively greater negative impact on the ecosystem.

Footnotes:

Wetlands include both tidal and non-tidal wetlands. The comparison may be conservative because, due to classification differences, seasonal wetlands are not included in the early 1800s historical mapping, but many *seasonal wetlands are in the modern mapping. Waterways include tidal channels, lakes, ponds, rivers, creeks, and intermittent streams. Tidal and non-tidal water bodies are not distinguished.*

Historical data sources: 1. Historical Ecology of the Sacramento-San Joaquin Delta Study. Draft data. San Francisco Estuary Institute-Aquatic Science Center for the California Department of Fish and Game. 2. Bay Area EcoAtlas. 1999. San Francisco Estuary Institute. Note: Detailed mapping of Suisun marsh is not available at this time.

Modern data sources: 1 Bay Area Aquatic Resources Inventory Dataset [geographic information system file type]. 2007-2011. San Francisco Estuary Institute; U.S. Bureau of Reclamation, MPGIS Service Center. 2. Delta Vegetation and Land Use. 2007. Aerial Information Systems, Inc. for the California Department of Fish and Game, Vegetation Classification and Mapping Program.



From Wetland to Agriculture to Encroachment by Developments. Over the past 160 years, the Delta has seen dramatic transformation, beginning with the conversion of wetlands to agricultural lands. Within the last 30 years, there has been a nearly two-fold increase in urban area. This rapid conversion of open space in the Delta, primarily agricultural land, to residential and commercial uses, raises concerns for the potential consequences on the Delta's water quality. The dramatically reduced extent of wetlands, compared to historical conditions, has diminished the system's capacity to filter contaminants while urban expansion has increased the inputs of some of those contaminants. The increase in open water since historical times is primarily attributable to the presence of several large flooded islands, such as Franks Tract, in the Delta today. The change in wetland extent in the last 30 years falls with the margin of mapping certainty stemming from different minimum mapping units and classifications.

Footnotes:

The agriculture/open space category includes all non-wetland native land cover, as well as agricultural (e.g., rice fields), fallow, and ruderal (with pioneering plants, after disturbance) land cover types. In the early 1800s period, this category consists entirely of native land cover that is not permanent wetland or open water. Urban area (purple) includes cities and suburb lands. The open water category includes all tidal channels, ponds, lakes, rivers, creeks, and streams, as well as areas classified as floating aquatic vegetation. The wetland category (green) includes all permanent wetlands. Seasonal natural wetlands are included in this category, however, for the two most recent time periods as they are not distinguished from other wetland types in the available geospatial layers.

Data sources: 1. Historical Ecology of the Sacramento-San Joaquin Delta Study. Draft data. San Francisco Estuary Institute/ Aquatic Science Center for the California Department of Fish and Game 2. Wetlands and Deepwater Habitats of the Conterminous United States, National Wetlands Inventory (NWI). 1985. U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC. URL http://www.fws.gov/wetlands/Data/DataDownload.html. 3. Land Use and Land Cover (LULC) data. 1974. Earth Resources Observation and Science (EROS) Center, United States Geological Survey. URL http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/LULC. 4. CALVEG77, 1977. United States Forest service and The California department of Forestry. URL http://www.fs.fed.us/r5/rsl/projects/gis/data/calcovs/CALVEG77.zip. 5. Delta Vegetation and Land Use. 2007. Aerial Information Systems, Inc. for the California Department of Fish and Game, Vegetation Classification and Mapping Program

5. FEATURE ARTICLES

a. Yolo Bypass Findings Could Help Wetland Managers Reduce the Methylmercury Problem

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Highlights

- ⇨ Wetlands promote the conversion of mercury to methylmercury, the most toxic form
- ⇨ Not all wetlands types and seasons are equal: there are methylmercury production "hot spots" and "hot moments", and a goal of ecosystem managers is to limit the frequency and magnitude of these
- ⇨ Seasonal wetlands undergoing extensive drying and rewetting, such as rice fields, emerge as potential mercury methylation "hot spots" compared to other types of wetlands
- ⇨ A recently completed study in the Yolo Bypass has provided multiple lines of evidence that mercury methylation and release downstream are enhanced during the wet winter months
- ⇨ Key management techniques include timing of water movement on and off wetlands, controlling fresh plant materials, and evaluating trade-offs between methylmercury moving downstream and impacting receiving

waters or remaining in place and potentially bioaccumulating in the wetland where it was created

⇨ Monitoring of methylmercury loads from wetlands should take into account 1) water flows, 2) dissolved vs. particulate phases in surface water, and 3) day/night cycles in surface water concentrations.

Flipside to Wetlands Restoration?

Over the past decade, scientists have learned quite a bit about mercury cycling in wetlands (**Sidebar**). It is well known that wetlands are capable of having the right "ingredients" to convert mercury to methylmercury, which is highly toxic to humans and wildlife. Further, it has been established that flooded soils can release methylmercury into the water. It may seem that more wetlands would then lead to more methylmercury in wildlife or released downstream, but that is not always the case.

Instead, recent studies in the Yolo Bypass and Cache Creek watershed suggest that there are "hot spots" and "hot moments" of methylmercury production. The studies show that wetland conditions vary in time and space, with large shifts in the relative importance of different processes responsible for methylmercury cycling. The findings from these studies support several key conclusions that are changing our picture of methylmercury production in wetlands.

- Sites of high mercury in sediment and water are not necessarily sites of high methylmercury concentration in sediment and water.

- Seasonally flooded wetlands may promote more methylmercury production compared to permanently flooded wetlands.

- There is a trade-off between minimizing methylmercury exports to receiving waters and minimizing methylmercury bioaccumulation inside a wetland's foodweb.

The Cache Creek Watershed: A Large Source of Methylmercury To The Delta

The Cache Creek watershed is a major source of mercury-contaminated sediment to the Yolo Bypass and the downstream Estuary (**Figure 1**). When the Yolo Bypass is conveying floodwaters, the Cache Creek Settling Basin may be responsible for enhanced methylmercury loading to the downstream Delta (Foe et al. 2008). The Cache Creek Settling Basin captures these mercury-containing sediments, but in a wetland-like environment that can promote mercury methylation. Monitoring has shown that, in an average year, the Cache Creek Settling Basin releases 160 g of methylmercury to the Delta (the estimated total from all Yolo Bypass sources is 578 g) and fish downstream of the Basin have methylmercury levels exceeding the EPA human consumption criteria (Slotton et al. 2002).

However, large loads of mercury don't always translate into high methylmercury levels. The data from Cache Creek Settling Basin suggest that the combination of mercury-laden sediment and wetlands may enhance the production and biological uptake of methylmercury (California Regional Water Board 2007, Slotton et al. 2002), but we have also learned that total mercury inputs are not always necessarily correlated with the amount of methylmercury produced in and exported from wetlands (see, for example, Marvin-DiPasquale et al. 2009a, Domalgalski et al. 2004). Thus, research is shifting from quantifying mercury sources and loads to studying methylmercury formation and transport.

Seasonal Wetlands Favor Methylmercury Production and Bioaccumulation

Recent studies suggest that seasonally flooded wetlands, those that undergo extensive drying and wetting, are potential mercury methylation "hot spots". In two studies from 2000-2006, USGS researchers studied the presence of methylmercury in surface water and sediment of the Cache Creek Settling Basin. Although they found a large amount of spatial and temporal variation in the wetlands' geochemistry and mercury cycling, one consistent pattern emerged: higher levels of methylmercury in seasonal wetlands compared to permanently flooded wetlands.

A fairly well accepted explanation for these patterns is that seasonal flooding tends to promote the activity of methylmercury-producing soil bacteria, whereas seasonal drying tends to promote the availability of sediment mercury pools for methylation. This conclusion is based on a host of studies from this region and others (for example, Bradley et al. 2011; Hall et al. 2008; Roulet et al. 2001). Certain types of bacteria are known to produce most of the methylmercury originating in wetlands (**Sidebar: Drivers of Methylmercury Exposure**). Across wetland environments, the conditions favoring methylmercury production are those in which the bacteria responsible are active and the ingredients the bacteria need to make methylmercury are in good supply. These conditions are common in seasonally flooded wetlands.

In contrast, even though permanently flooded wetlands have active bacteria -- and thus the potential to methylate mercury – ingredients for making methylmercury may be less readily available. For example, mercury in permanent wetland sediments tends to be strongly bound to organic, sulfur-rich particles, limiting its availability for bacterial uptake. Permanent ponds without rooted plants are particularly low in net methylmercury production, as their soils are often low in microbially available mercury and organic carbon. Further, due to the lack of emergent plants, reduced shading allows degradation of methylmercury by sunlight, thus reducing export.

Fish in seasonally flooded wetlands also tend to accumulate more methylmercury than those on permanently flooded areas (Ackerman and Eagles-Smith 2009), although this does not necessarily apply to all components of wetland foodwebs. As shallow surface waters pass through seasonal wetlands such as rice fields, methylmercury levels in the water may increase by an order of magnitude, due partially to methylmercury production but largely to evaporative concentration. Dr. Collins Eagles-Smith's USGS research team noticed correlations between dissolved methylmercury concentrations and fish tissue concentrations (Eagles-Smith, personal communication), suggesting that bioaccumulation in pelagic fish may be associated with water concentrations. Bioaccumulation in invertebrate organisms, in contrast, is not clearly associated with water column concentrations and may be more associated with sediment concentrations. Thus, understanding the controls on methylmercury bioaccumulation requires an understanding of the specific foodweb pathways involved.

Controls of Methylmercury Production and Transport

With a range of wetland types and flow regimes, the Yolo Bypass and Cache Creek Settling Basin are well-suited for studies on the factors that influence mercury methylation and export. Over the past decade, work by multiple organizations (CDFG, Moss Landing Marine Laboratories, U.C. Davis, USGS) has indicated the importance of seasonal and land use-related drivers, such as crop and water flow management. Two recently completed studies in the Yolo Bypass (Windham-Myers et al. 2010, Heim et al. in review) have provided multiple lines of evidence that mercury methylation and export were enhanced during flooding of seasonal wetlands, and that winter months were a significant period of production and export.

Experimental work in agricultural and managed wetlands of the Yolo Bypass Wildlife Area (Windham-Myers et al. 2010) suggests that, in addition to oxygen availability, carbon supply is a significant driver of methylmercury production across field types and seasons. During summer, limitation of photosynthetic inputs (plant biomass) of organic carbon, by devegetation, reduced organic carbon pools typically used by bacteria (e.g. "food" molecules occurring in porewater, such as acetate) by 84% and bacterial mercury-methylation by 49% among all Yolo Bypass wetland types (Windham-Myers et al. 2009). During the winter season, sediment methylmercury concentrations were at their highest in agricultural wetlands (3-6 nanograms, or parts per trillion, methylmercury per gram dry weight) and methylmercury production rates correlated with of the amounts of crop residues and porewater acetate (Marvin-DiPasquale et al, in review). Compared with other wetland types of the Yolo Bypass and Cache Creek Settling Basin, seasonal wetlands of the Yolo Bypass had among the highest concentrations of sediment methylmercury, porewater dissolved organic carbon and porewater acetate during winter. After a pulse at initial flooding, these sediment concentrations generally declined over the winter months (Marvin-DiPasquale et al, 2009a; Marvin-DiPasquale et al. in review).

Wesley Heim and a team from Moss Landing Marine Laboratories (MLML) recently completed a study of best management practices to reduce methylmercury concentrations and exports from seasonal wetlands in the Yolo Bypass Wildlife Area. Their results further support the importance of the winter months for methylmercury production: concentrations of methylmercury in most of the seasonal ponds studied had an initial peak occurring in fall followed by a decrease and a leveling off after January. Heim and his colleagues suggest that the high concentrations of methylmercury released from seasonal wetlands may be mitigated in one of two ways: 1) by reducing methylmercury production by reducing available plant biomass (for example, by allowing more grazing), and 2) treatment of seasonal wetland outflows in so-called "polishing ponds", permanent wetlands with slow flows that are subject to greater rates of sedimentation and degradation by sunlight.

Ultimately, the net flux of methylmercury from wetlands varies as a function of source water concentrations, water flow rates, soil and water properties (e.g. organic carbon content and quality), and physical conditions (e.g. solar radiation). Net rates of methylmercury production and export may thus be regulated by control of these factors, where possible.

What is Controlling the Rate of Methylmercury Production in Wetlands?

The two primary on-site controls of methylmercury production are chemical and biological: oxygen availability and the release of microbially available organic carbon from decomposing plants and algae. Both promote the activity of methylmercury-producing bacteria, but their influence on methylmercury production depends on whether a wetland is dry or flooded. Dry conditions that promote oxygen availability also promote mercury availability, but they inhibit the activity of mercury-methylating bacteria. On the other hand, the flooded conditions that promote plant decomposition, and thus carbon availability, promote methylation but over time limit the pool of available mercury, as it becomes bound to freshly released organic and sulfur-rich particles. Therefore, within the whole spectrum of wetland types from open water to dry fields, those at the extreme ends are the least likely places for net methylmercury production, and those in the middle– seasonally flooded fields – the most likely places.

What is Controlling the Rate of Methylmercury Export?

The two primary controls on methylmercury export rates are physical and chemical: water flows, controlling the physical transport of methylmercury offsite, and constituents such as sediment grain size and dissolved organic carbon (DOC), controlling the solubility of methylmercury in water. Methylmercury export rates increase with high flows, as they stimulate diffusive and advective flux from sediments and limit the time available for internal removal processes such as particle settling and photodemethylation (Heim et al., in review). An additional important control is the distribution of methylmercury between the dissolved and particulate phases of sediment and surface water (Marvin-DiPasquale et al. 2009b). Greater amounts of DOC in the water and coarse-grained sediments promote porewater-to-surface water export rates by enhancing the mobility of sediment-bound methylmercury (Marvin-DiPasquale et al. 2009b). Further, Bergamaschi and colleagues (2011) were able to predict methylmercury exports from tidally exchanged surface waters based on a strong relationship between DOC and dissolved methylmercury.

Ways to Reduce Methylmercury Production and Exports

Based on the new findings, the most promising options for reducing methylmercury production are controls applied to water flows and organic carbon. With mercury present, conditions in wetlands are often conducive to the net production of methylmercury. Therefore, a continued goal of managing methylmercury in wetlands will be to limit export.

Flow Management

Promoting Internal Aqueous Methylmercury Removal Processes. Flow management, such as slowing water flow and recycling water between fields, can be used to promote internal methylmercury removal processes in wetlands. These management practices take advantage of a range of methylmercury removal processes occurring in the water, including settling of methylmercury-containing particles, downward movement of water by plant root activity (evapotranspiration), and methylmercury degradation by sunlight.

However, there is also a drawback to slowing flows. While slowed flows will help enhance internal methylmercury removal processes, they may increase methylmercury concentrations inside a wetland and its tailwater (water immediately downstream), leading to greater bioaccumulation in these water bodies and concerns for the wildlife feeding there. This will be exacerbated, for example, in warm weather, if evaporation from a field with slowed flows further concentrate methylmercury in the surface water. Available controls are discussed in the *Tailwater Treatment* section below.

Preventing Direct Release During First Flush, Such as by Routing Tailwater Through Holding Ponds. The most effective way to reduce methylmercury exports from seasonal wetlands is to limit releases during the first flush following a dry period. Dry soils that have been previously flooded contain some of the highest levels of methylmercury. When flooded again, these soils rapidly release their methylmercury into the water. Capturing the pulses of high methylmercury flows at the beginning of the growing season, and upon drawdown and decay, and subjecting them to a filtering process may be a way to control "hot moments". See *Tailwater Treatment* section below.

Management of Methylmercury Production

Preventing Buildup of Methylmercury in Soils. To prevent a buildup and subsequent flux of methylmercury out of sediment, net methylmercury production in sediment would need to be reduced. Landscape scale alterations of flow regime and carbon availability (see below) are promising pathways for reducing net methylmercury production.

Amendment approaches have also been suggested, particularly those that chemically limit the availability of mercury for methylation, such as through the addition of reduced iron (Ullrich and Sedlak, 2010). Amendment experiments, however, show extreme variability in their results and indicate that responses of natural wetlands to amendments will be highly unpredictable. Depending on conditions at the onset of an application, an amendment could either stimulate or inhibit methylation rates (Marvin-DiPasquale, unpublished data, personal communication).

Organic Carbon Management

Removing Organic Matter From Soil Surfaces. Limiting plant growth and litter on freshly flooded seasonal wetlands – and thereby limiting carbon sources for bacteria - may be one way to limit methylmercury production, particularly in the winter. Two recent studies by USGS and MLML provide evidence that living and decaying plants provide fuel for mercury methylation and point to litter residue removal and enhanced grazing by waterfowl and other plant eaters as possible control options.

First, lab experiments by the USGS using soils from permanent and seasonal wetlands in the Cache Creek Settling Basin and Yolo Bypass indicate that methylmercury production was greatest following the addition of acetate (Marvin-DiPasquale , unpublished data), a metabolic compound that is released by living and decaying plants. And more recently, field experiments by USGS (Windham-Myers et al. in review) showed that seasonal patterns of methylmercury production are linked to acetate abundance.

Second, results from MLML studies support grazing as a possible control option. Heim and colleagues (in review) demonstrated that surface water concentrations of methylmercury in the winter are lower on fields that had been grazed by cattle, compared to non-grazed fields. They also report that fresh plant litter stimulates methylmercury production in laboratory settings. These results indicate that removal of surface litter may be a way to limit methylmercury production and exports from wetlands during winter, which may be the most difficult window to control. Finally, although this technique may be promising, understanding the net effect of carbon limitation on other important ecosystem processes, such as habitat support for migrating waterfowl, is an important caveat to consider.

Tailwater Treatment

Tailwater treatment has emerged as a promising control option. MLML scientists are assessing management options for maximizing methylmercury removal in permanent wetlands used as tailwater treatment ponds. A filtering technique that also may be applied to tailwaters is the coagulation of mercury and methylmercury bound to organic matter using metal based salts (Henneberry et al. 2010).

Landscape Manipulation

Several ongoing studies within the Delta watershed assess possible control options on the landscape scale. A two-year study on wetlands and rice fields of the Cosumnes

River Preserve (CRP) is underway to test whether carbon management – by removal of rice straw and plant surface litter through discing or bailing – can limit methylmercury production within these agricultural wetlands. Further, the CRP study is testing whether the seasonality of flooding (winter vs. summer) may be used to regulate annual methylmercury fluxes, by decoupling periods of production from export. Both studies seek to determine whether load reductions are achievable, and if so, whether increased on-site biota exposure is a consequence of limiting export.

One surprise finding for all studies thus far is the importance of winter as a "hot moment" in methylmercury production and export. Summer solar radiation may warm soils and stimulate bacterial activity, but as the new studies show, it also reduces the reactivity of mercury pools and enhances the degradation of methylmercury. The primary period of methylmercury export from the Yolo Bypass Wildlife Area is during winter flooding when overall microbial activity and methylmercury production in agricultural soils is fueled by the decomposition of grasses and rice straw, and when flow is maximal.

Implications for Management and Monitoring

Findings from multiple linked studies in the Cache Creek Settling Basin and Yolo Bypass Wildlife Area point toward important conclusions that can aid in management and monitoring of methylmercury dynamics in wetlands. Some key management choices:

- *The Timing of Water Movement On and Off Wetlands.* This includes flow-through during flooding periods as well as the interplay of wetting and drying. Initial and final flushes of methylmercury from wetland soils are "hot moments" during which targeted water control may capture methylmercury and remove some or all of it prior to export. Slowing flow-through and recycling water between fields or into tailwater ponds are other ways of promoting internal processes of methylmercury removal prior to export.
- *Control of Fresh Carbon Sources.* Organic carbon at the sediment surface is important to ecosystem energy flow and, as such, it also is the fuel for

mercury methylating microbes. Controlling this carbon pool prior to flood-up may be a means of limiting methylmercury production.

- *Evaluating Trade-offs.* A major problem to focusing on export loads is a lack of attention to methylmercury exposure of *in situ* biota. Local wetland food webs will likely be affected negatively by flow alterations and carbon management. Increasing water residence time can promote evaporative concentration of methylmercury in the water column, thus potentially increasing accumulation in biota within the wetland. Reductions in carbon may reduce methylmercury production but will likely reduce energy flow and may reduce forage for over-wintering wildlife populations.

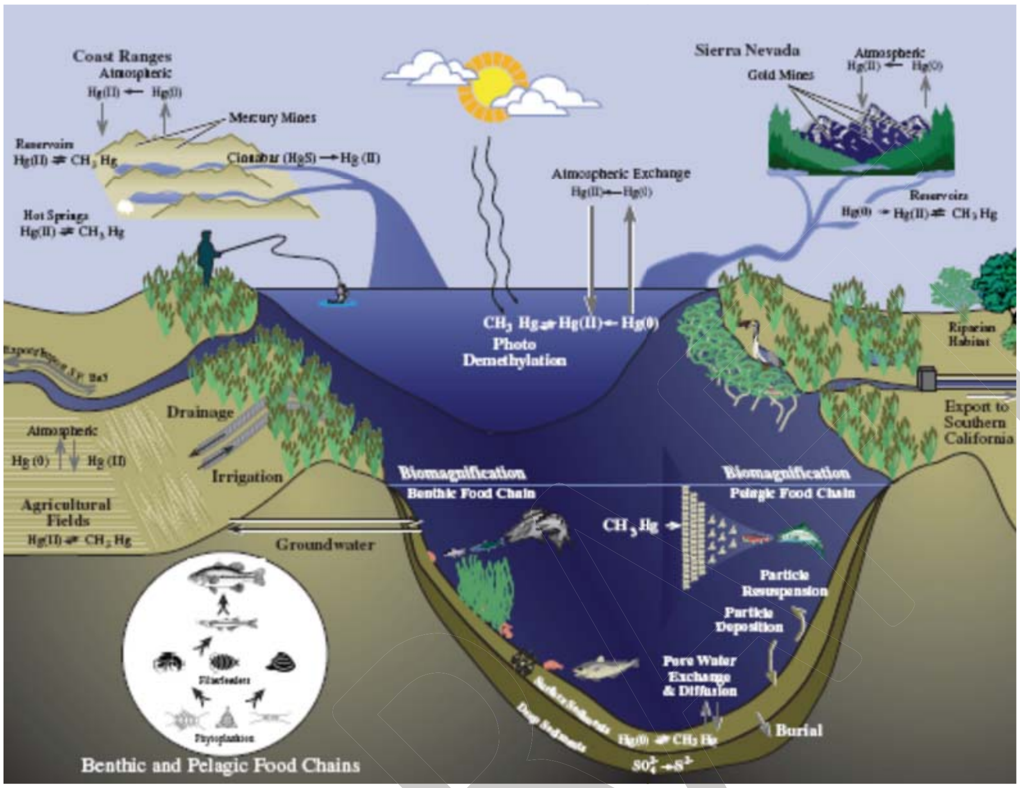
The recent studies identified three critical information needs that should be considered when developing monitoring plans to improve calculations of methylmercury loads from wetlands: 1. water flows, 2. methylmercury distribution in the water column (bound to suspended soil particles vs. dissolved), and 3. day/night variability in surface water methylmercury concentrations.

- Having accurate information on flows is critical to calculating accurate loads from wetlands. For example, rice fields can differ greatly in their flow patterns (constant flow vs. varied flow), flow paths (plug flow vs. well mixed), and rates of transpiration and evaporation (Bachand et al., in review).
- Methylmercury partitioning (the ratio of methylmercury bound to suspended particles vs. dissolved methylmercury) is critical in predicting processes of export and removal. Understanding how and why different flow regimes promote methylmercury removal requires independent measurement of particulate and dissolved concentrations.
- Day/night dynamics can strongly affect methylmercury concentrations in surface water (**Figure 2**). Physical processes that affect methylmercury concentrations are different between day and night. Daytime concentrations of methylmercury in water are often lower than nighttime concentrations due to photodemethylation and downward hydrologic flow caused by plant transpiration. Thus, daytime measurements of surface water methylmercury

concentrations may underestimate daily average concentrations in both open water and vegetated environments.

SIDEBARS

1. Drivers of Methylmercury Exposure



Footnote: Figures from Foe et al. (2003).

Legend

CH3Hg	methylmercury
DOC	dissolved organic carbon
Hg^0, Hg(0)	elemental mercury
Hg(II)	mercury(II), ionized mercury.

Methylmercury exposure – via supply, production and degradation – is regulated by complex conditions that move and transform mercury. In wetlands, mercury attached to suspended particles in water can settle onto the bottom sediments where it can diffuse back into the water, be resuspended, be buried by other sediments, or be methylated (converted to methylmercury). Methylmercury can be taken up by biota, stored, and transferred up the food chain, or broken down (demethylated) by bacteria or sunlight, at which point the elemental mercury can be released to the atmosphere (volatilization). Dissolved organic compounds originating from plants enhance the solubility of mercury in water, thus making it more likely to remain in the water and enter the food chain.

Mercury methylation in wetlands is primarily attributed to the activity of bacteria in sediments and is believed to be an accidental consequence of a metabolic process. From lab experiments we have learned that two primary ingredients are necessary for bacteria to methylate mercury: "reactive" mercury and sufficient available carbon (bacterial energy source, in the form of fresh plant material and litter) to support microbial growth.

Rates of methylmercury production, transport, and accumulation in biota vary strongly over time and space. The relative importance of different factors affecting methylmercury cycling are described in more detail in the Mercury Conceptual Model developed for the Delta Regional Ecosystem Restoration Implementation Plan (DRERIP, Alpers 2008),

More information:
http://science.calwater.ca.gov/pdf/drerip/DRERIP_mercury_conceptual_model_final_012408.pdf

Illustrations

Figure 1.

Studies in the Cache Creek Settling Basin and the Yolo Bypass, selected to cover a range of wetland types and flow regimes, have contributed to improved understanding of methylmercury bioaccumulation and exports to the Delta. The studies have assessed the effects of land use and flow management. The majority of wetlands in the Cache Creek Settling Basin (just upstream of where Cache Creek enters the Yolo Bypass Flood Conveyance zone) and Yolo Bypass are seasonal or intermittently flooded wetlands and include rice fields and protected wildlife habitat.

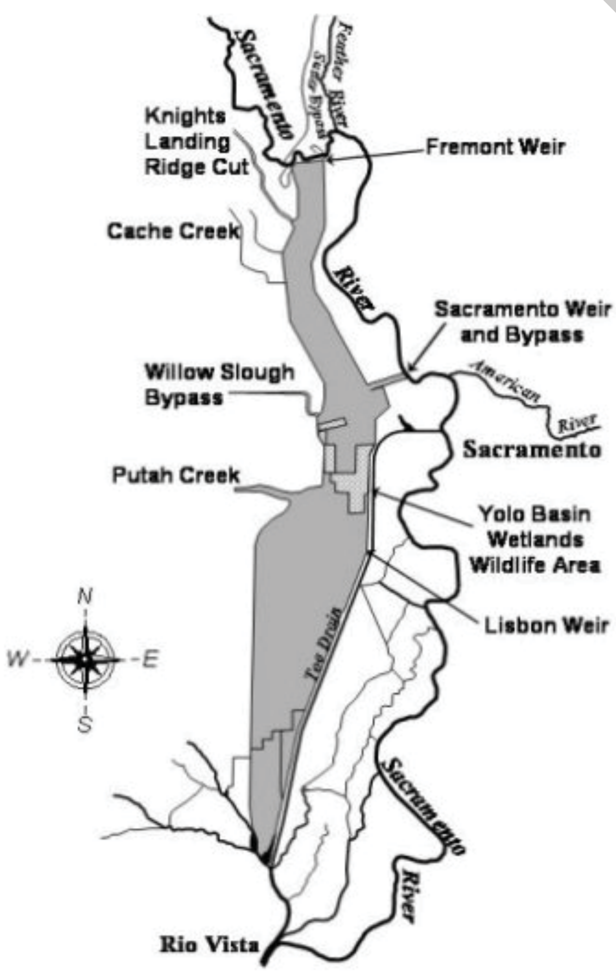
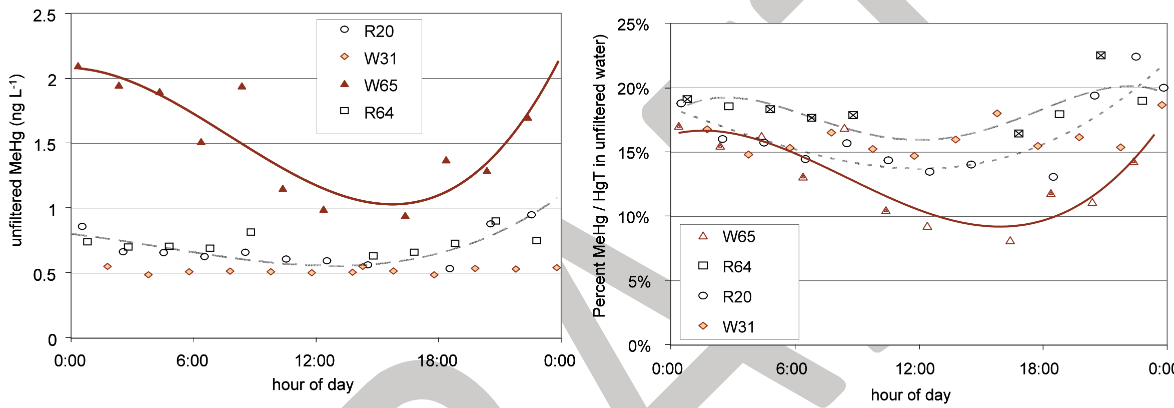


Figure 2. Water methylmercury concentrations were lowest during the day and highest at night.

Scatterplot showing the change in water methylmercury concentrations over a 24 hour cycle, both as a) unfiltered methylmercury and b) percent methylmercury (methylmercury/total mercury)(Fleck et al. in review). Relative methylmercury concentrations during the day were lower than concentrations at night for three of four fields studied. These patterns are likely due to breakdown by sunlight (photodemethylation) and surface water drawdown to the sediment caused by plant transpiration. The day/night effect may be more pronounced in summer and in wetlands where surface water methylmercury is predominantly in a dissolved form.



Footnote: curves shown are polynomial fits of the data to illustrate general trends. W65 and W31 (solid lines) represent wild rice fields and R20 and R64 (dashed lines) represent white rice fields.

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b. The Interagency Ecological Program – Cooperative Ecological Investigations in the Bay-Delta Estuary since 1970

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Highlights

- ⇨ The current mission of the Interagency Ecological Program (IEP) is, in collaboration with others, to provide ecological information and scientific leadership for use in management of the Bay-Delta.
- ⇨ The Bay-Delta Estuary is at an important crossroads. Environmental managers must determine what a desirable future ecosystem would look like, how it would function, and how it can be established.
- ⇨ IEP science informs long-term, cooperative management solutions, such as the Delta Plan and the Bay-Delta Conservation Plan.
- ⇨ The discovery of the Pelagic Organism Decline and research into its causes is a good example of the kinds of critical information the IEP can provide to Estuary managers.
- ⇨ Like the Bay-Delta ecosystem, the IEP has been changing and what it will look like in the future is now being decided.
- ⇨ The California Water Quality Monitoring Council, in partnership with the IEP and others, has established a web portal for information on the health of the Bay-Delta Estuary.

Science Informs Solutions

The Interagency Ecological Program (IEP) for the San Francisco Estuary is a long-term state and federal science partnership that conducts cooperative ecological investigations in the Delta and in San Francisco Bay.

The IEP was founded in 1970 to implement, coordinate, and integrate scientific activities in the Estuary that were then carried out by two state and two federal agencies. The goal was to provide better scientific information to managers and decision-makers about changes in the ecosystem. The original focus was on the effects of operating the State and Federal water projects on fish and wildlife. The water projects include large storage and flood control reservoirs on nearly all tributary rivers to the Delta, a network of channels and gates that route water through the Delta, and two large pumping facilities in the southwestern part of the Delta that export fresh water to the San Joaquin Valley and southern California (see **Companion Article: Small Vessels, Big Changes**).

Over time, the focus and membership of the IEP has broadened – the IEP "Science Tree" has grown (**Sidebar: The IEP "Science Tree": Science for Application**). The IEP now has six federal and three state member agencies (see **Figure 1**). IEP teams include scientists, managers, and policy makers from

- all IEP member agencies,
- two partner organizations (Delta Stewardship Council and San Francisco Estuary Institute),
- universities,
- stakeholder groups,
- private companies, and
- the public.

Together, they represent much of the Bay-Delta's "science family."

The current mission of the IEP is, in collaboration with others, to provide ecological information and scientific leadership for use in management of the San Francisco Estuary. IEP science is long-term and cooperative "science for application." It is intended to inform management solutions for the Estuary such as the two long-term

Delta plans that are currently under development by the Delta Stewardship Council and by a multi-entity group (**Sidebar: Big Plans for the Delta**). IEP science includes monitoring, research, modeling, analysis, and synthesis (**Sidebar: 2011 IEP Projects**). Communication of results is essential if IEP Science is to be used by managers. IEP science results are communicated in many ways, for example on the IEP web site, in the quarterly IEP Newsletter, and in IEP reports, journal publications, and presentations at the annual IEP meeting and elsewhere.

One recent example of IEP science is the IEP "Pelagic Organism Decline" (POD) investigation. IEP fish monitoring showed a sudden, steep decline in four pelagic fish species in the Delta and Suisun Bay in 2002. Research into possible causes was initiated in 2005. It is currently thought that multiple interacting environmental drivers have caused the POD and that it may represent a rapid shift to a new, unfavorable ecological regime. Rapid ecological regime shifts are often the result of gradual long-term changes that accumulate until the system reaches a tipping point. Understanding the long- and short-term changes that lead up to regime shifts is essential to finding ways to ameliorate or reverse them.

The Value of Long-Term Monitoring and Collaboration

The long-term monitoring conducted by the IEP is essential for detecting both slow and rapid ecological changes such as past declines in fish populations (Thomson et al. 2010) or those that may happen in the future, for example due to climate change (Cloern et al 2011). Detecting and understanding changes affecting the Delta ecosystem also require ongoing collaborative and multi-disciplinary analysis and synthesis of IEP and other available data. The POD investigation, for example, included work with the National Center for Analysis and Synthesis (NCEAS) in Santa Barbara, California. The IEP collaboration with NCEAS also led to a new system for finding, understanding, and effectively using the diverse IEP data. This system combines the "Metacat" software developed at NCEAS with Google maps and is expected to come on-line in 2012.

IEP Roles, Partners, and the Future of the Delta

The IEP and the Bay-Delta ecosystem are now at an important crossroads that will define their futures. For the ecosystem, the questions are what a more desirable future ecosystem regime would look like and how it would function, how and if such a regime could be established and maintained, and if it would have enough resilience to persist in the face of climate change, continued species invasions, changing water demands, and other changes. Scientific information collected by the IEP will be critical to answering these fundamental questions. The IEP may also be called upon to serve as a coordinator or collaborative partner in several major initiatives revolving around adaptive management of the Bay-Delta ecosystem and California water, including the Delta Plan and the Bay-Delta Conservation Plan (**Sidebar: Adaptive Management Depends On Science**).

The IEP recently formed a partnership with the California Water Quality Monitoring Council's new California Estuary Monitoring Workgroup. This group is developing an on-line "web portal" with information about the ecological health of the San Francisco Estuary and other California estuaries (**Sidebar: A New Way to See the Delta**). The IEP also continues to partner with the Delta Stewardship Council's Delta Science Program and the San Francisco Estuary Institute. A partnership with the State and Federal Water Contractors Science Program is evolving. The IEP is also currently reinvigorating its long-standing partnership with the California Water and Environmental Modeling Forum (CWEMF). CWEMF is a non-profit organization that was formed in 1994 to increase the usefulness of models for assessing California's water-related problems. For many years, the IEP and CWEMF held back-to-back annual meetings with a jointly held "overlap" day at the Asilomar State Conference Center in Pacific Grove. Recent travel restrictions for State agencies interrupted these highly valued joint meetings, but they will resume in 2012 in Folsom.

In the near future, the IEP may gain new member agencies that would bring new information needs, stakeholders, and science programs to the IEP science partnership. This may include the Central Valley Regional Water Quality Control Board with its developing Delta Regional Monitoring Program (RMP) for Contaminants (see Management Update: Delta RMP, page XX). Closely coordinating and integrating the Delta RMP's contaminant-focused monitoring with existing IEP monitoring and research will allow quantitative assessments of contaminants effects on fish and other organisms monitored by the IEP (e.g., Brooks et al. 2011). Data and information cooperatively produced by the IEP and Delta RMP could be displayed and accessed on the California Estuary Web Portal and would fill a critical gap in tracking and understanding the ecological health of the Estuary. It would also better connect water quality information provided by the Bay and Delta RMPs with the biological information provided by the IEP and help inform management strategies and science plans for the whole estuary.

These new members, partnerships, and roles pose questions for the IEP that are quite similar to the questions for the ecosystem: what should the future IEP look like and how will it function and persist? The IEP started a conversation about its future at its 2010 annual meeting; the conversation continues. To learn more about the IEP visit its website or come to the 2012 annual meeting, taking place April 18-20, 2012 at the Lake Natoma Inn in Folsom, CA. The annual CWEMF meeting will take place April 16-18 at the same location.

DWR • USBR • USFWS • SWRCB • DFG • USGS • NMFS • USACE • USEPA

Interagency Ecological Program

COOPERATIVE ECOLOGICAL INVESTIGATIONS SINCE 1970

The IEP was founded in 1970 and has six Federal and three State member agencies. Federal member agencies are the National Marine Fisheries Service (NMFS), U.S. Army Corps of Engineers (USACE), U.S. Bureau of Reclamation (USBR), U.S. Environmental Protection Agency EPA, U.S. Fish and Wildlife Service (USFWS), and U.S. Geological Survey (USGS). State member agencies are the California Department of Fish and Game (DFG), Department of Water Resources (DWR), and State Water Resources Control Board (SWRCB).

SIDEBARS

1. The IEP "Science Tree": Science for Application

The French scientist Louis Pasteur famously wrote: "No, a thousand times no; there does not exist a category of science to which one can give the name applied science. There are science and the applications of science, bound together as the fruit to the tree which bears it" (Pasteur 1871).

The IEP conducts science that informs practical policy and management applications. The fruits of the IEP science tree are solutions for the San Francisco estuary.

The success and longevity of the IEP science tree are rooted in the strong commitment of the IEP member agencies and partners to science cooperation. The IEP's cooperative technical, coordination, and review teams grow out of this commitment. The IEP teams form the solid trunk that supports the IEP science tree's crown. The crown has three large branches that support smaller branches and leaves:

- monitoring,
- research, and
- modeling.

Monitoring tells what is happening, research tells why something is happening, and modeling helps tell what can happen.

- Analysis,
- synthesis, and
- communication of the results

form the tree's smaller branches and leaves. They are needed to understand and tell the whole story. All parts are needed to let the IEP science tree bear fruit for consumption by policy-makers, managers, and the public.

The IEP science tree has grown to its current size and shape over more than four decades. Many dedicated arborists have cultivated it. They include IEP leaders such as the late Dr. Randy Brown who in his down to earth way defined the IEP as: "Our mission is to get the science nailed down" (Randy Brown in DWR People 1998). They also include the many dedicated IEP scientists and field and lab technicians such as Sally Skelton (born Davis). She discovered a new zooplankton species in the Delta, which was named *Oithona davisii* in her honor, and continues to share her expertise in zooplankton taxonomy with the IEP even after her retirement from the Department of Fish and Game.

More information: http://www.water.ca.gov/iep/

“There are no such things as applied sciences, only applications of science”

- Louis Pasteur, French chemist and microbiologist who created the first vaccine for rabies and anthrax (September 11, 1872)

““Our mission is to get the science nailed down”

- Dr. Randy Brown (in DWR People, 1998)

2. Big Plans for the Delta

The Delta is an important place for many people and there are many large and small plans for its future. Currently, two especially large planning efforts are under way to achieve the "co-equal goals" of "providing a more reliable water supply for California and protecting, restoring, and enhancing the Delta ecosystem." The co-equal goals were written into California law by the Sacramento–San Joaquin Delta Reform Act of 2009. They are to be achieved "in a manner that protects and enhances the unique cultural, recreational, natural resource, and agricultural values of the Delta as an evolving place" (CA Water Code §85054). Science and adaptive management (**Sidebar: Adaptive Management Depends on Science**) are important components of both plans.

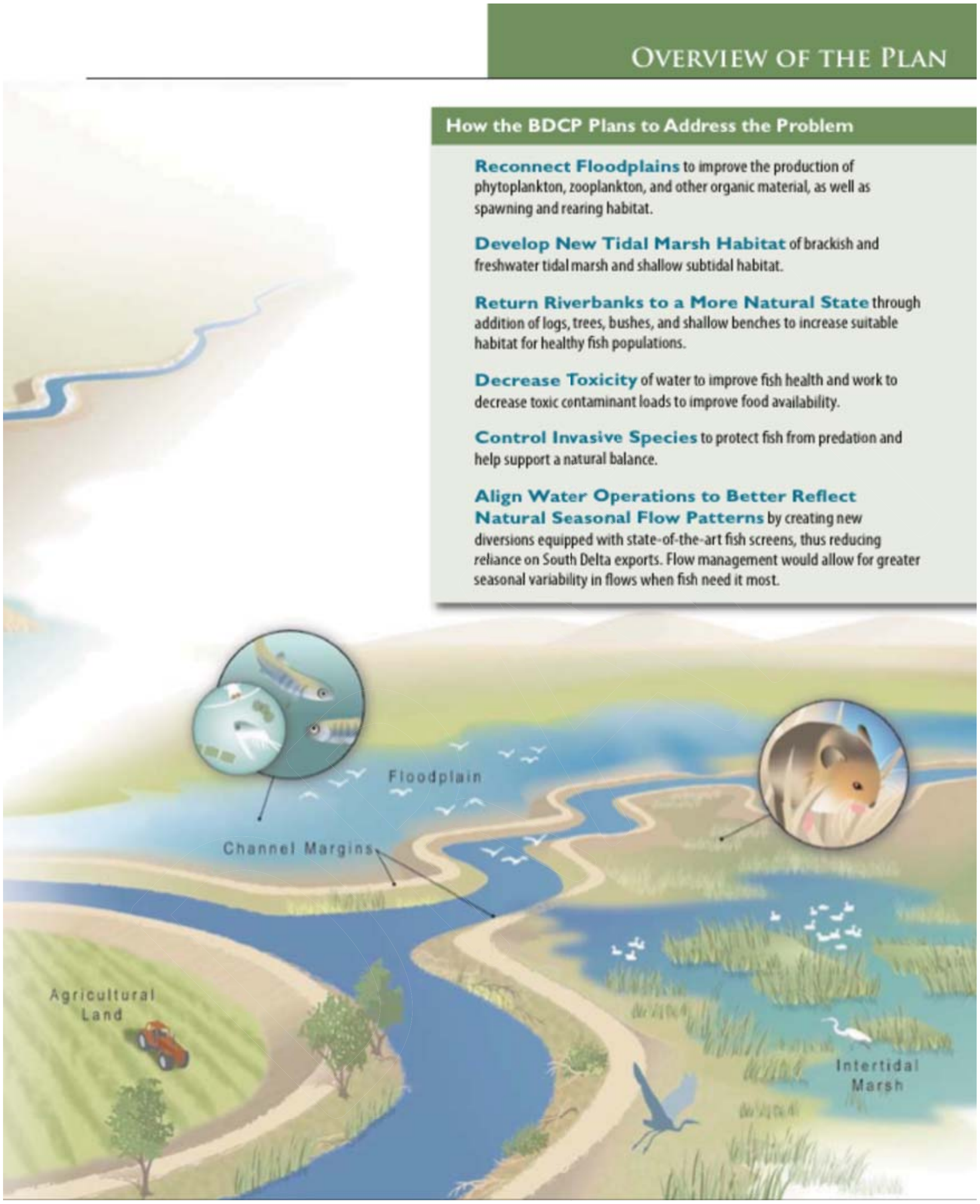
1. The Delta Stewardship Council is developing the **Delta Plan**. The Delta Plan is intended as a "foundational, adaptable, practical, and enforceable" plan for addressing all aspects of Delta management throughout the entire 21st century.

2. Multiple agencies and other organizations are developing the **Bay Delta Conservation Plan (BDCP)**. This plan is aimed at large-scale improvements in water conveyance and ecosystem restoration in the Delta over the next 50 years, in a way that will preserve threatened and endangered species. The BDCP is intended to eventually become a component of the Delta Plan, but it first has to meet a number of requirements, including those in California Water Code Section 85320.

There are also many other plans for Delta management. The Delta Plan will be used as a point of reference for many other planned activities in the Delta. Determining consistency will be a major role of the Delta Stewardship Council, once the Delta Plan has been completed.

More information: http://deltacouncil.ca.gov/ and http://baydeltaconservationplan.com/Home.aspx

The Delta Plan is being developed to achieve the coequal goals of protecting and enhancing the Delta ecosystem, and providing for a more reliable water supply for California in a manner that protects and enhances the Delta as an evolving place.


OVERVIEW OF THE PLAN
How the BDCP Plans to Address the Problem
Reconnect Floodplains to improve the production of phytoplankton, zooplankton, and other organic material, as well as spawning and rearing habitat.
Develop New Tidal Marsh Habitat of brackish and freshwater tidal marsh and shallow subtidal habitat.
Return Riverbanks to a More Natural State through addition of logs, trees, bushes, and shallow benches to increase suitable habitat for healthy fish populations.
Decrease Toxicity of water to improve fish health and work to decrease toxic contaminant loads to improve food availability.
Control Invasive Species to protect fish from predation and help support a natural balance.
Align Water Operations to Better Reflect Natural Seasonal Flow Patterns by creating new diversions equipped with state-of-the-art fish screens, thus reducing reliance on South Delta exports. Flow management would allow for greater seasonal variability in flows when fish need it most.
Floodplain
Channel Margins
Agricultural Land
Intertidal Marsh

3. 2011 IEP Projects

In 2011, the IEP coordinated and tracked 144 projects with a combined budget of $39 million. These projects fell into three large program categories:

IEP Core Program – Bay-Delta monitoring that provides key long-term and real-time data sets used in many studies, status and trends assessments, daily water project operations, and for regulatory purposes. Monitoring includes water quality, phytoplankton, benthic invertebrates, zooplankton, and fish. Most of this monitoring is required by State Water Right Permits or Federal Biological Opinions for the coordinated operation of the State and Federal Water Projects (OCAP). 2011 program: 30 projects, $16.8 million. URL: http://www.water.ca.gov/iep/activities/monitoring.cfm

IEP Pelagic Organism Decline (POD) Program – an integrated set of studies to investigate the causes of the steep decline of two native and two non-native pelagic fish species in the Bay-Delta. The POD program is currently broadening its scope to include other species and biological communities in the Bay-Delta. 2011 program: 34 active projects, $4.5 million. URL: http://www.water.ca.gov/iep/pod/

IEP Coordinated Studies Program – additional short-term studies and some monitoring not funded by the IEP but relevant to achieving its mission and goals. This includes studies funded by the Delta Science Program (http://www.deltacouncil.ca.gov/science-program) and the CALFED Ecosystem Restoration Program (http://www.dfg.ca.gov/ERP/). It also includes studies selected by the Federal Task Force (which was set up to coordinate federal and state efforts to better manage water supplies in California) and monitoring required by the Central Valley Project Improvement Act (CVPIA, http://www.usbr.gov/mp/cvpia/index.html). IEP coordination helps make these independently funded studies more efficient and effective. 2011 program: 80 active projects, $17.8 million. http://www.water.ca.gov/iep/activities/research.cfm

4. Adaptive Management Depends on Science

Adaptive management takes action when the outcome is uncertain. Adaptive management includes a learning process that uses many branches of science. Modeling helps in choosing the most promising actions by predicting their effects. Monitoring determines whether the chosen action achieves its goals. Hypothesis-driven experimentation and research is particularly useful when working to shrink large uncertainties about existing conditions and potential management outcomes. Analyses, synthesis, communication of results close the loop. Adaptive management means actions may be continued, abandoned, or adjusted. As with the IEP science tree, adaptive management must be rooted in and supported by close cooperation among decision-makers, managers, scientists, stakeholders, and the public (**Sidebar: The IEP "Science Tree": Science for Application**).

The IEP has supported adaptive management of the Estuary since before the ecologists C.S. Holling and Carl Walters coined the term in the late 1970s. Older examples include providing fish data and information that are used to adjust weekly and longer-term water project operations. A new example is the IEP's involvement in implementing the science plan included in the "Fall Outflow Adaptive Management Plan" (U.S. Bureau of Reclamation 2011). Adaptive management of outflow from the Delta to San Francisco Bay in the fall is required under the 2008 Delta Smelt Biological Opinion (U.S. Fish and Wildlife Service 2008). The scientific evaluation of the effectiveness of the currently required fall outflow levels may lead to adjusted levels that help better serve the co-equal goals of water supply reliability and ecosystem health. In the future, IEP science will likely also play a large role in adaptive management required under the Delta Plan and Bay-Delta Conservation Plan (**Sidebar: Plans to Help The Delta**).

More information about adaptive management:

- in the Draft Delta Plan: http://www.deltacouncil.ca.gov/delta-plan (see chapter 2)
- recommended by independent advisors for the BDCP: http://www.bdcpweb.com/Libraries/Background_Documents/BDCP_Adaptive_Management_ISA_report_Final.sflb.ashx

- of water project operations: http://www.water.ca.gov/swp/operationscontrol/calfed/index.cfm
- in the Delta Smelt Biological Opinion: http://www.fws.gov/sfbaydelta/ocap/

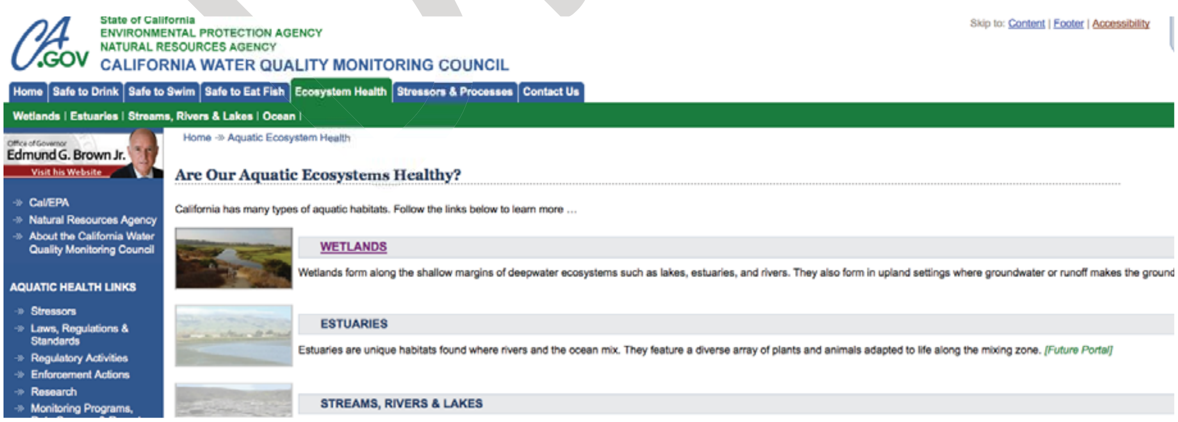
A Nine-step Adaptive Management Framework for the Delta. The shading represents the three broad phases of adaptive management (Plan, Do, and Evaluate and respond), and the boxes represent the nine steps within the adaptive management framework. The circular arrow represents the general sequence of steps. The additional arrows indicate possible next steps for adapting (for example, revising the selected action based on what has been learned.).

Source: Fifth Staff Draft Delta Plan (Delta Stewardship Council 2011)

5. The Estuaries Portal - A New Way to See the Delta

A 2006 California Senate Bill (SB 1070) required California agencies to integrate and coordinate their water quality and related ecosystem monitoring, assessment, and reporting. This led to the establishment of the California Water Quality Monitoring Council (Council) in 2007. The Council is making water quality information available to the public through an online portal called "My Water Quality." Portal content is provided by the Council's workgroups. The recently formed "California Estuary Monitoring Workgroup" will initially focus its efforts on the San Francisco Bay-Delta Estuary and will provide content for a new California Estuaries Portal. The first steps include identifying key questions to assess the ecological health of the San Francisco Bay-Delta Estuary, the data and methods available and needed to address the questions, and the methods to access, display, and work with the data and information. In the process of developing this Portal, the Workgroup is also expected to identify redundancies, data gaps, and inefficiencies in current monitoring activities and develop solutions for improvements and better data integration. The IEP is a lead participant in the work group and an important data and information provider for the Portal, along with other science partners from the Delta and Bay.

More information:
http://www.waterboards.ca.gov/mywaterquality/monitoring_council/estuary_workgroup/
and http://www.waterboards.ca.gov/mywaterquality/



The California Estuary Monitoring Workgroup is developing an Internet portal focused on the health of the San Francisco Bay-Delta Estuary.

c. COMPANION ARTICLE

1. 200 Years of Small Boats and Big Changes

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The IEP agencies share a fleet of 32 monitoring and research vessels used to document and investigate changes in the Delta ecosystem. The Department of Water Resources-owned Research Vessel (RV) San Carlos is the IEP's primary water quality monitoring vessel and one of the its longest serving vessels. The RV San Carlos set out on her maiden voyage from San Diego, CA, in early 1976. After stops in Morro and Monterey Bays, the 56-foot, 48-ton, custom-built ship entered San Francisco Bay in February 1976 and soon commenced her IEP service in the Delta under Captain Lloyd Brenn. Today, the RV San Carlos is captained by Eric Santos and is used to document changes in Bay-Delta water quality, plankton, and benthic invertebrates as well as for various special studies. She will be replaced by a new *RV San Carlos* in the next few years.

Some of the changes in the Estuary seen since the arrival of the RV San Carlos in 1976 have been dramatic. For example, numbers of native zooplankton species and diatoms have plummeted while those of non-native zooplankton, jellyfish, and clams have soared. Aquatic weeds and harmful blue-green algal blooms have become commonplace. Water quality has also changed – some constituents such as inorganic nitrogen have greatly increased while others such as phosphorus and suspended sediments have decreased (Jassby 2008). But the new RV San Carlos is just the latest in a line of small research vessels that have tracked big changes in the Bay and Delta.
The first one of these small vessels was the 79-foot Spanish "paquebot" (supply ship) San Carlos, after which the RV San Carlos was named. The original San Carlos sailed from San Diego and Monterey to San Francisco almost exactly two centuries before the maiden voyage of the RV San Carlos. In August 1775 she became the first European ship to enter San Francisco Bay. Her captains Juan Manuel de Ayala and Jose Joaquin Moraga were the first Europeans to map San Francisco and San Pablo Bay, Suisun Bay, and the western Delta. The arrival of the San Carlos brought big changes to San

Francisco Bay, but the Delta remained relatively uncharted and unchanged over the next five decades. During this period, California had a population of less than 10,000 Europeans, but at least 150,000 Native Americans, many of whom lived in and around the Delta where they hunted native fish, shellfish, waterfowl, and seals in canoes made from native tule reeds that grew abundantly in the Delta's expansive wetlands. Tules were also used to build homes and weave baskets. The lives of these Native Americans were so closely linked with the wet Delta environment that to one early ethnologist they appeared "almost amphibious" (Powers 1877).

The rapid transformation of the Delta arguably started in August 1839 when two small schooners (sail boats), the 22-ton Isabella and the smaller Nicolás, along with a four-oared row boat, made their way from San Francisco up the Sacramento River to the mouth of the American River. The schooners belonged to the wealthy American merchant Nathan Spear and were commanded by his 17-year-old nephew William "Kanaka Bill" Heath Davis. On board was the Swiss immigrant John Augustus Sutter with a few German and Hawaiian companions and a bulldog. Sutter had chartered the vessels to explore the Delta in search of land for other European immigrants. Sailing through the Delta's labyrinthine waterways, it took the three boats several days of searching to find the mouth of the Sacramento River. After more than a week, they finally reached the mouth of the American River, where Sutter established "New Helvetia", which later became the city of Sacramento. Davis reports that upon their arrival at this site, they encountered "some seven or eight hundred Indians … in canoes made of tules." Davis returned to San Francisco the next day. He gave a vivid description of the Delta as he saw it from the Isabella that day: "As we moved away Captain Sutter gave us a parting salute of nine guns—the first ever fired at that place—which produced a most remarkable effect. As the heavy report of the guns and the echoes died away, the camp of the little party was surrounded by hundreds of Indians, who were excited and astonished at the unusual sound. A large number of deer, elk and other animals on the plains were startled, running to and fro, stopping to listen, their heads raised, full of curiosity and wonder, seemingly attracted and fascinated to the spot, while from the interior of the adjacent wood the howls of wolves and coyotes filled the air, and immense flocks of waterfowl flew wildly over the camp" (Davis 1929, http://www.sfgenealogy.com/sf/history/hb75yb.htm).

The schooner Isabella made several more trips up and down the Sacramento River. In 1840 and 1841 her owner, Nathan Spear, followed an invitation by John Sutter to go salmon fishing in the Sacramento River. He reportedly filled the hold of the Isabella with large numbers of fish, which he sold for a profit in San Francisco. The Isabella thus became the first commercial salmon fishing vessel on the west coast.

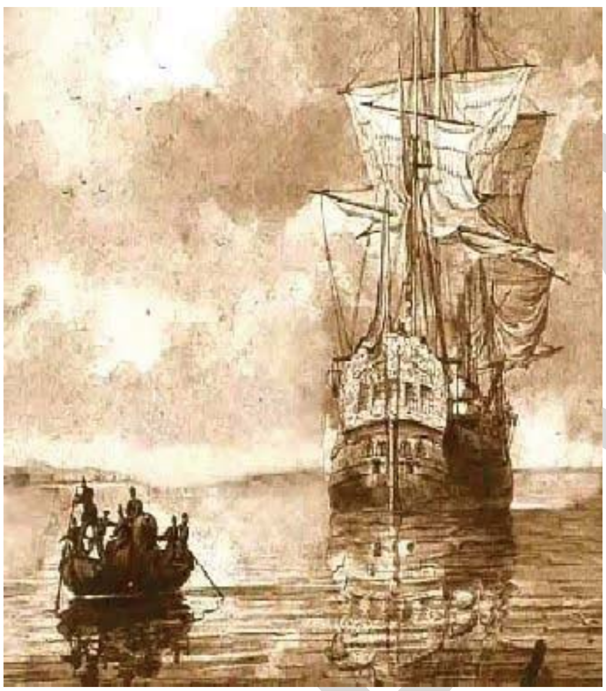
On November 28, 1847, the small 37-foot vessel “Sitka” became the first steamboat in the still largely pre-European Delta landscape. No one foresaw then the dramatic transformations that would begin just two months later, on January 24, 1848. That day, James Marshall was building a sawmill for John Sutter when he accidentally discovered gold on the south fork of the American River. Marshall’s discovery started the great human mass migration to California that became known as the California gold rush. Within a year, 100,000 adventurers from all over the world rushed into California. By 1860, the non-Native American population of California had risen to almost 400,000 while the Native American population had plummeted to 30,000. This sudden change in human demographics and cultural backgrounds changed California forever. And nowhere were the changes greater than in the California Delta.

When the Isabella first sailed up the Sacramento River, the Delta was a 700,000-acre mosaic of diverse landscape types and components. Large flood basins occupied by both tidal and non-tidal wetlands dominated the north Delta landscape, many large and small tidal islands covered the central Delta, and the South Delta was a complex landscape of river branches, secondary overflow channels, and habitat patches (**Sidebar: Using the Past Delta to Inform the Future**). Historical Delta landscape patterns varied predictably along physical gradients. Change was driven by tides, river flows, seasons, and the Delta’s variable Mediterranean climate. Native Americans had long learned to live with these cyclical changes. They also changed the Delta landscape themselves to increase animal and plant production. But these historical changes preserved the overall character of the Delta landscape. In contrast, the changes that began with the first Delta voyage of the schooner Isabella in the mid-19th century fundamentally altered the Delta landscape. Today, Ayala, Moraga, Davis, Sutter, and their contemporaries would hardly recognize it as the same place that they saw from the San Carlos and the Isabella.

When Eric Santos and his IEP colleagues stand on the bridge of the current RV San Carlos, they can see across 1,115 miles of artificial levees onto large tracts of agricultural lands that have replaced most of the historical tidal wetlands and islands. Drained peat soils have subsided and the land elevation of many agricultural islands is now lower than the water elevation in the channels through which the RV San Carlos travels on its monthly monitoring cruises. Over the years, the IEP crews on the RV San Carlos have seen several breached levees and flooded islands. A few flooded islands were never drained and are now artificially large, open lakes. The dynamic, branching river channels of the past gave way to a static and almost linear grid of straightened canals with steep and often rip-rapped banks several decades before the RV San Carlos arrived in the Delta. These artificially interconnected canals are used for north to south and east to west water conveyance and shipping. The once highly dynamic water flows have also changed. Most tributary rivers flowing to the Delta have been dammed and diked. This has made the flows coming into the Delta more predictable, with much fewer extremely high or low flows. Pumping of water from the Delta to the San Joaquin Valley and Southern California often leads to reversed (upstream) net flows in the channels of the central and southern Delta. Frequently, the amount of fresh water from the Delta that is pumped south is greater than the amount of Delta water that flows into San Francisco Bay. Flow alterations have led to changes in water clarity, increased salinity in the Bay, and a spatially constricted and more stable low salinity zone in the western Delta (Baxter et al. 2010, Enright and Culberson 2010, Shellenbarger and Schoellhamer 2011, Schoellhamer 2011). Other large changes in the Delta include deteriorating water quality due to increasing pollution by chemical contaminants and nutrients, and several waves of successful non-native species invasions that may have made the San Francisco Estuary "the most invaded estuary in the world" (Cohen and Carlton 1998) and have fundamentally changed the Delta's food web.

Not surprisingly, the dramatic changes in the Delta and its watershed over the past 160 years have had many ecological consequences. When the original San Carlos and Isabella plied the waters of the Delta, salmon and sturgeon were the kings of the rivers and the Delta, huge flocks of migrating birds darkened the skies, and elk and pronghorn still roamed the land. Today, non-native striped and largemouth bass have edged out the native salmon. Migrating birds, while still quite plentiful, no longer darken the skies, and human crops, cattle, and roads now cover the land. The most recent, rapid changes in the Delta have been described as an “ecological regime shift” (**Sidebar: Regime Shift in the Delta**). But this shift is only the latest in a series of dramatic changes that started 160 years ago and continue to this day. More changes are expected in response to Delta management plans (**Sidebar: Big Plans for the Delta**), changes in human water and land uses, additional species invasions, and global climate change. And there will likely be unanticipated causes of additional change. Nobody knows exactly what these changes will be. But small vessels, including the successor of the RV San Carlos, will continue to witness these big changes and monitor and study their effects.

More information about the RV San Carlos: http://www.water.ca.gov/bdma/sancarlos/history.cfm



The San Carlos was the first European ship to enter the San Francisco Estuary.

San Carlos

Owned and operated by the California Department of Water Resources, the modern RV San Carlos is IEP's primary research vessel for water quality monitoring.

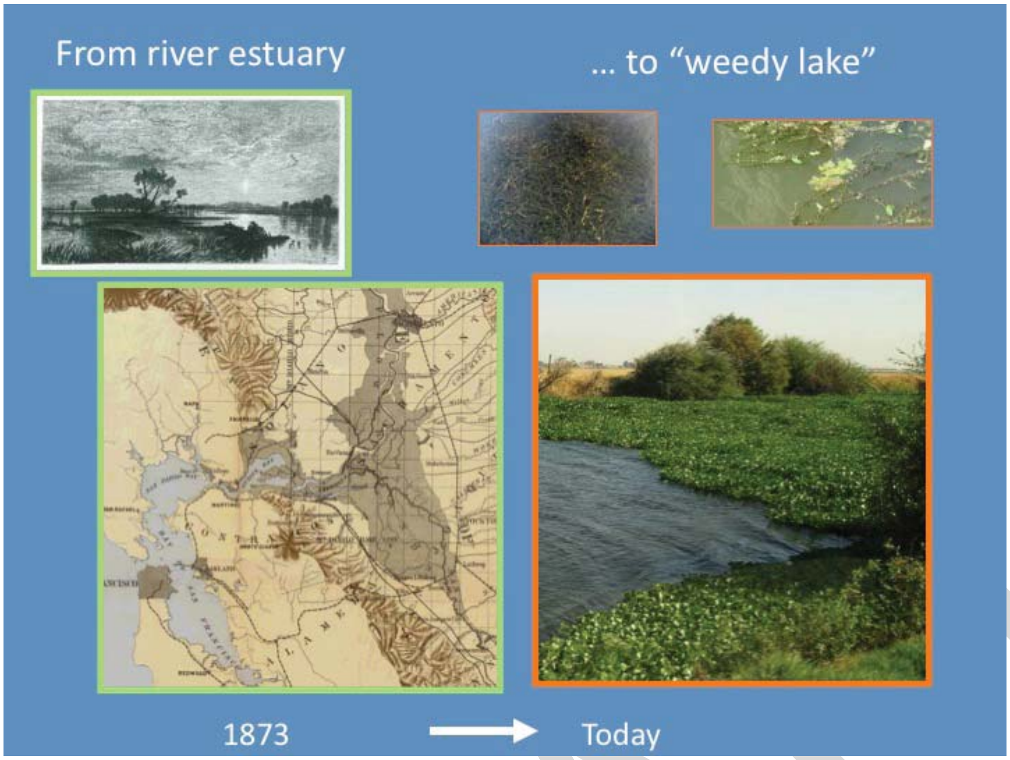
A depiction of the native south Delta, along the San Joaquin River, shows winding channels, grasslands, and tule marshes, supporting populations of tule elk, sandhill cranes, white-faced ibises, white pelicans, and various ducks and geese. Original artwork by Laura Cunningham, 2010. [Courtesy of BayNature – granted we get permission to reuse].

SIDEBARS

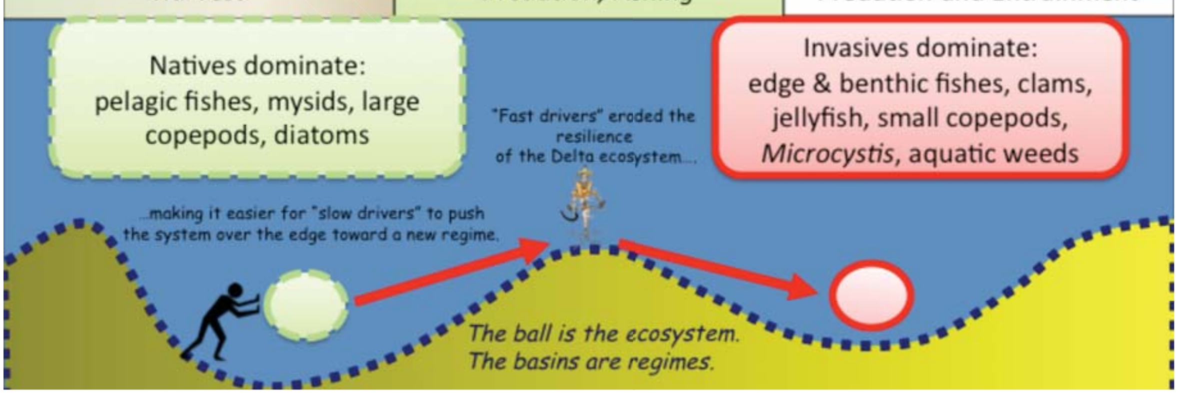
C1. Regime Shift in the Delta

The IEP developed several conceptual models to help explore and understand the reasons for the recent "Pelagic Organism Decline" (POD) in the Delta (Baxter et al 2010). Conceptual models attempt to identify the important components of a system and determine how they affect each other. The current conceptual model posits that the POD represents a rapid ecological "regime shift" that followed a longer-term erosion of ecological resilience. This model is currently guiding ongoing and future investigations. The hypothesis is that environmental drivers that changed slowly over decades ("slow drivers") eroded the resilience of the Delta ecosystem and made it more vulnerable to the effects of drivers that changed more rapidly around the time of the POD. According to this model, the slow drivers include Delta outflow and salinity, configuration of the Delta landscape, water temperature, turbidity, nutrients, contaminants, and direct mortality of the POD fishes due to "harvest" (fishing, predation, and entrainment into the water project pumping facilities).

More information: http://www.water.ca.gov/iep/pod/synthesis_results_workplans.cfm



Environmental Drivers	Old Regime	New Regime
Outflow	*Variable, High*	*Variable, Lower*
Salinity gradient	*To the west, Variable*	*To the east, Constricted*
Landscape	*Complex, Variable*	*Simplified, Rigid*
Temperature	*Low, Variable*	*High, Uniform*
Turbidity	*High, Variable*	*Low, Less variable*
Nutrients	*High phosphate, low nitrogen*	*Low phosphate, High nitrogen (NH_4+)*
Contaminants	*Few, Low*	*Many, High*
"Harvest"	*Predation, Fishing*	*Predation and Entrainment*



C2. Using the Past Delta to Inform Its Future

Despite broad recognition of the need to take decisive action to restore the Delta ecosystem, determining what to do where remains particularly challenging. In a place that has been altered so significantly, the most sustainable and effective actions are not obvious. We know that restoration should be performed on a large scale and not piece-meal, should take advantage of existing physical processes, and should include interconnected habitats and heterogeneous habitat mosaics (CDFG et al. 2010, Moyle et al. 2010). But when it comes to developing priorities and making decisions, there is often little guidance available. Improving our understanding of historical conditions can address some of these uncertainties, allowing us to better identify fundamental restoration principles, including the effects of large-scale restoration on various aspects of water quality (e.g., nutrient availability, primary production, chemical transformations; Dahm et al. 1995, Swetnam 1999, Turner 1995)

The Aquatic Science Center (ASC), in collaboration with the California Department of Fish and Game, has developed an early 1800s land cover map of the Delta. The map and an accompanying report will be finalized in the upcoming months. This work provides a glimpse into the rich landscapes of the natural Delta and offers clues to the processes that formed and maintained certain features and patterns. This new view of the Delta can be used to reset assumptions about the past, interpret the ecological functions of the historical landscape, identify priority functions and habitat mosaics for particular locations, determine measures of restoration success, and contribute to guiding landscape visions (Mika et al. 2010, Atwater 2011).

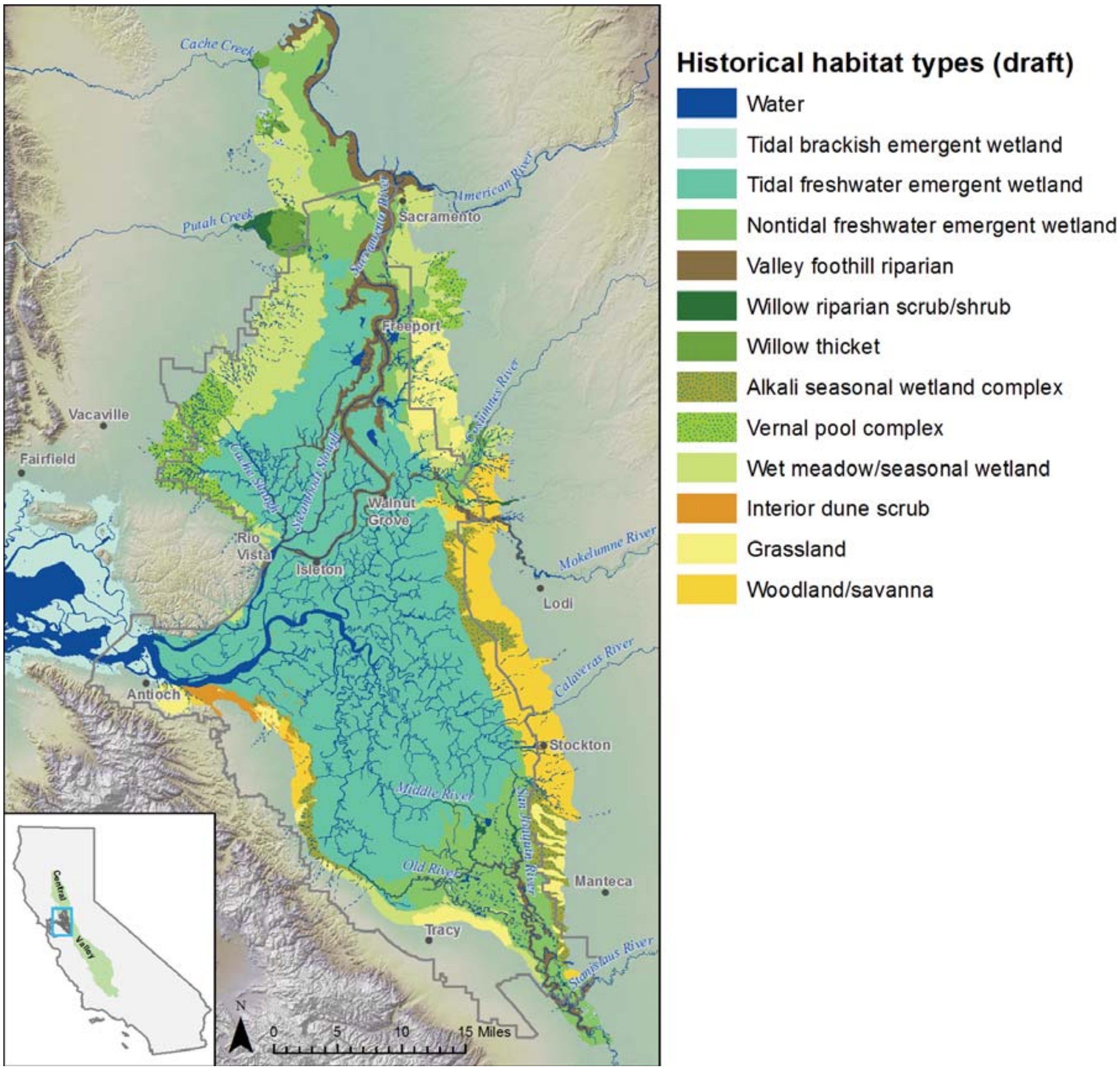
What was the Historical Delta Like?

The Delta prior to Euro-American modification was diverse at many scales: complex habitat mosaics were arranged in distinct patterns across broad physical gradients. Over 350,000 acres of tidal freshwater wetlands lay at elevations just below high tide, and well over 1,000 miles of tidal channel wove across the plain. In the central Delta, the landscape was arranged in large islands of emergent vegetation and willows intersected by networks of sinuous tidal channels and to the west by sand mounds rising above the tides. Extending north along the Sacramento River, broad zones of tidal wetland graded into non-tidal wetlands within flood basins. Broad riparian forests bordered the flood basins, positioned along the river channels. The basins received annual overflow, a portion of which was retained in ponds and lakes and slowly released through the summer months. Such conditions provided important habitat for fish and waterfowl and increased capacity for nutrient exchange between the aquatic and wetland environments. The tidal margins of the south Delta along the San Joaquin River were less defined as basins, consisting of a maze of former meander bends and active and abandoned channels. This floodplain landscape was flooded in the spring by snowmelt delivered by the San Joaquin River and largely dry by late fall. Locally-complex habitat patterns existed, where riparian forest lining channel banks and patches of willow thicket, seasonal wetlands, and grassland intermixed with expanses of tule and perennial and intermittent ponds.

Supporting a Landscape-Level Restoration Framework

The science of restoration ecology has shown that selecting and prioritizing restoration actions within a landscape framework, using landscape ecology principles, is critical to re-establishing ecological functions (Simenstad et al. 2006, Greiner 2010). Historical information can be the foundation of a landscape framework for identifying restoration strategies in the contemporary and projected future Delta, not as restoration templates (given current constraints and future climate change), but as insight into what, where, and how future functional patterns may be supported. In 2012, a new SFEI/ASC project funded by the Department of Fish and Game will address these needs by describing aspects of the historical Delta and relating them to important ecological functions in ways directly relevant to planning and management. Development of landscape-level conceptual models, guiding principles, and metrics (that help define what "large and interconnected" means) will provide tools with which managers can better evaluate and prioritize actions. This project will also produce graphics and illustrations that present possible future landscapes of the Delta. Together, this information can help establish more resilient, functional habitat mosaics that have the capacity to adapt along with projected future physical changes (for example, those brought by climate change, sea level rise, and changing land and water use). The goal is not to recreate the past, but to develop new ideas and options that are more likely to provide the benefits we need in terms of ecological function, flood protection, and water quality (Kondolf et al. 2001, Walter and Merritts 2008).

More information: http://www.sfei.org/DeltaHEStudy



Habitat type extent and distribution in the early 1800s Delta. This map, developed using historical sources, shows broad patterns of habitats arranged across topographical, hydrological, soil, and tidal gradients. A forthcoming explanatory report documents in detail the historical habitat characteristics of the Delta prior to significant Euro-American modification. The historical perspective can facilitate the identification of patterns and processes relevant to restoration and planning.

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Photos

IEP Directors panel on the future of the IEP at the 2010 meeting. Photograph by Bill Templin, DWR.

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